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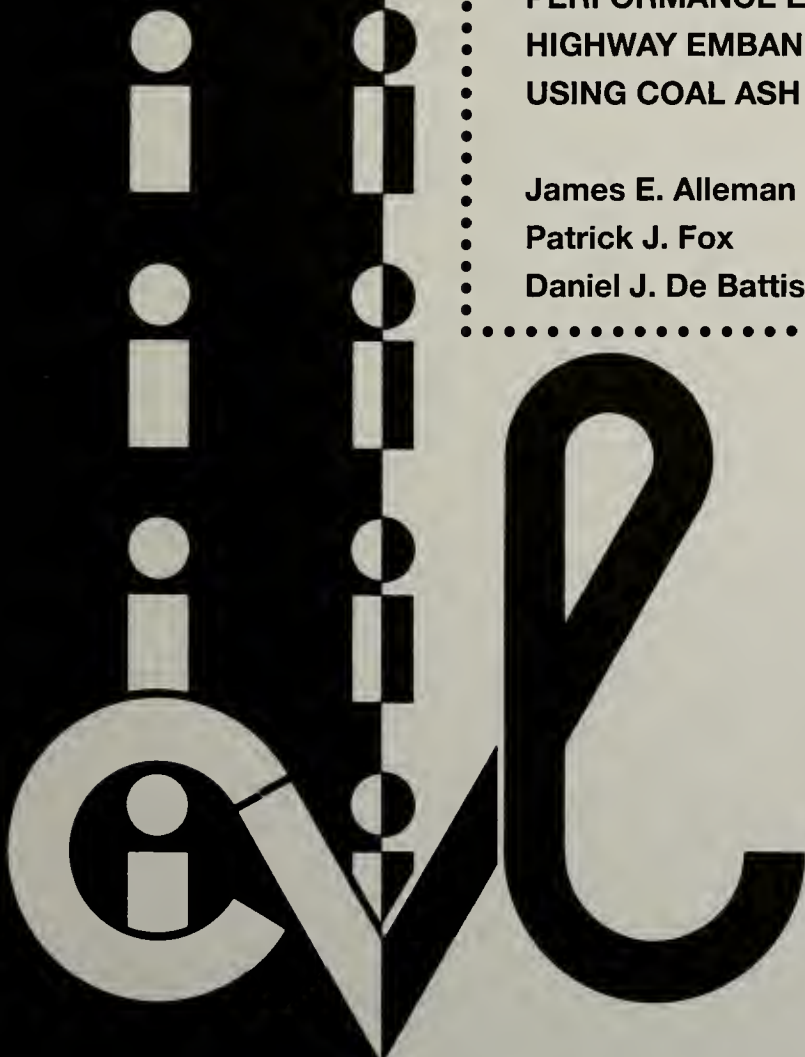
DEPARTMENT OF TRANSPORTATION

JOINT HIGHWAY RESEARCH PROJECT
FHWA/IN/JHRP-96/5

Final Report

PERFORMANCE EVALUATION OF
HIGHWAY EMBANKMENT CONSTRUCTED
USING COAL ASH

James E. Alleman
Patrick J. Fox
Daniel J. De Battista



PURDUE UNIVERSITY

FINAL REPORT

FHWA/IN/JHRP-96/5

PERFORMANCE EVALUATION OF HIGHWAY EMBANKMENT
CONSTRUCTED USING COAL ASH

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Joint Highway Research Project

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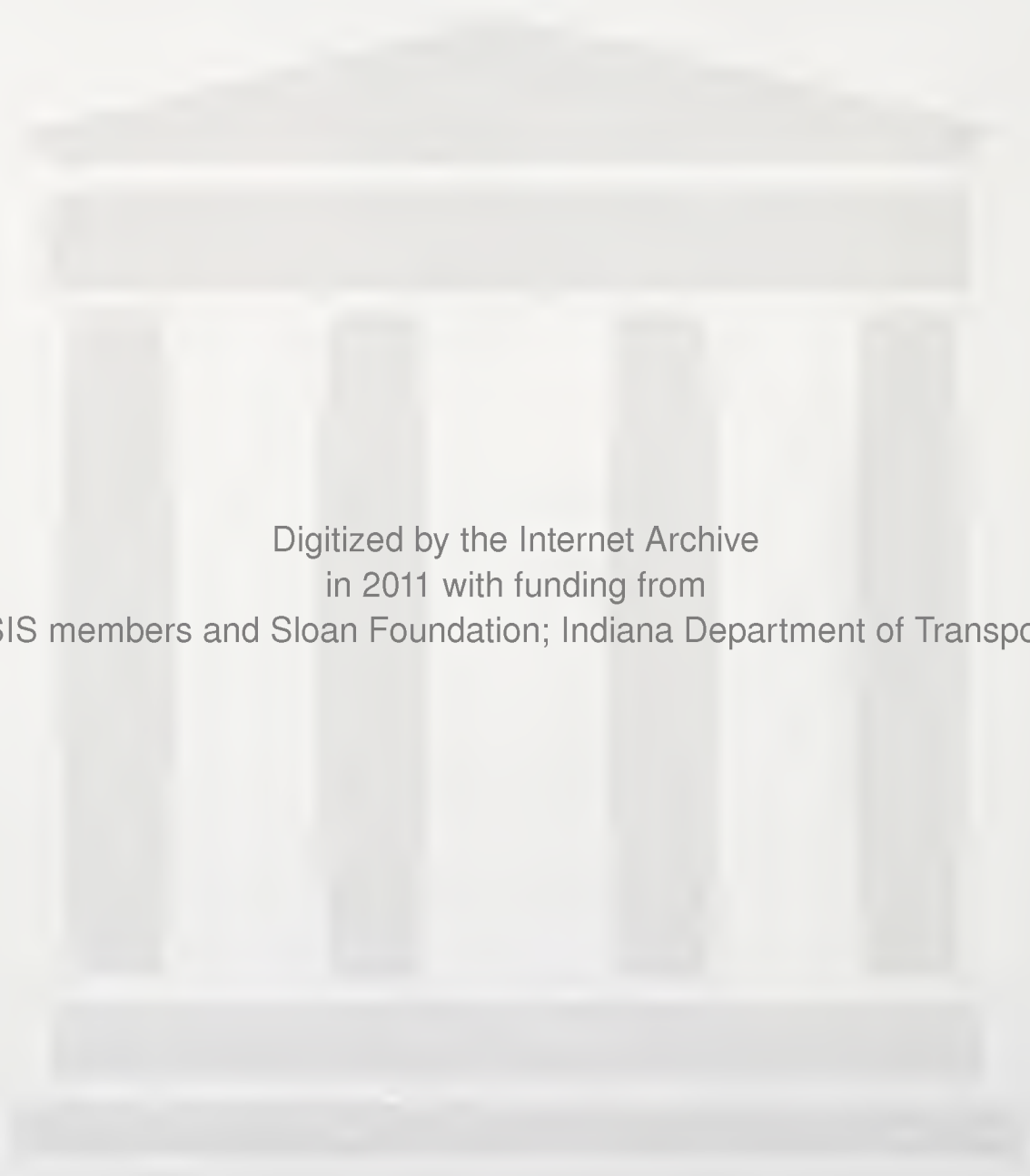
Prepared as Part of an Investigation Conducted by the

Joint Highway Research Project
Purdue University

in Cooperation with the
Indiana Department of Transportation
and the
U.S. Department of Transportation
Federal Highway Administration

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16. Abstract The objective of this project was to assess the environmental and geotechnical performance of two highway embankments constructed using coal combustion fly ash. The environmental work focused on characterizing monitoring well water samples from the site before, during, and after construction. In addition, a number of <i>in-situ</i> lysimeter water samples were also tested during and after construction. In each case, water samples were evaluated in terms of their constitutive organic and metal concentrations, as well as their relative bioassay response using a Microtox™ protocol. The geotechnical work included monitoring of ash water content and unit weight during placement, settlement analysis, and <i>in-situ</i> testing of the completed ash fills using the Standard Penetration Test. Analysis of the groundwater and lysimeter water samples indicated that the coal ash had not adversely affected the environmental quality of the 56th Street overpass site. The embankments also performed well from a geotechnical perspective both during and after construction. The only difficulty was the measurement of coal ash water content and unit weight using the nuclear density gauge. The benefits of reusing coal combustion fly ash for highway construction are: 1) low-cost source material for INDOT, ii) reduced disposal costs for Indiana utilities, and iii) savings of Indiana landfill capacity.			
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- Alt & Witzig Inc., (Indianapolis, Indiana) – installed the groundwater sampling wells.
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CHAPTER 1

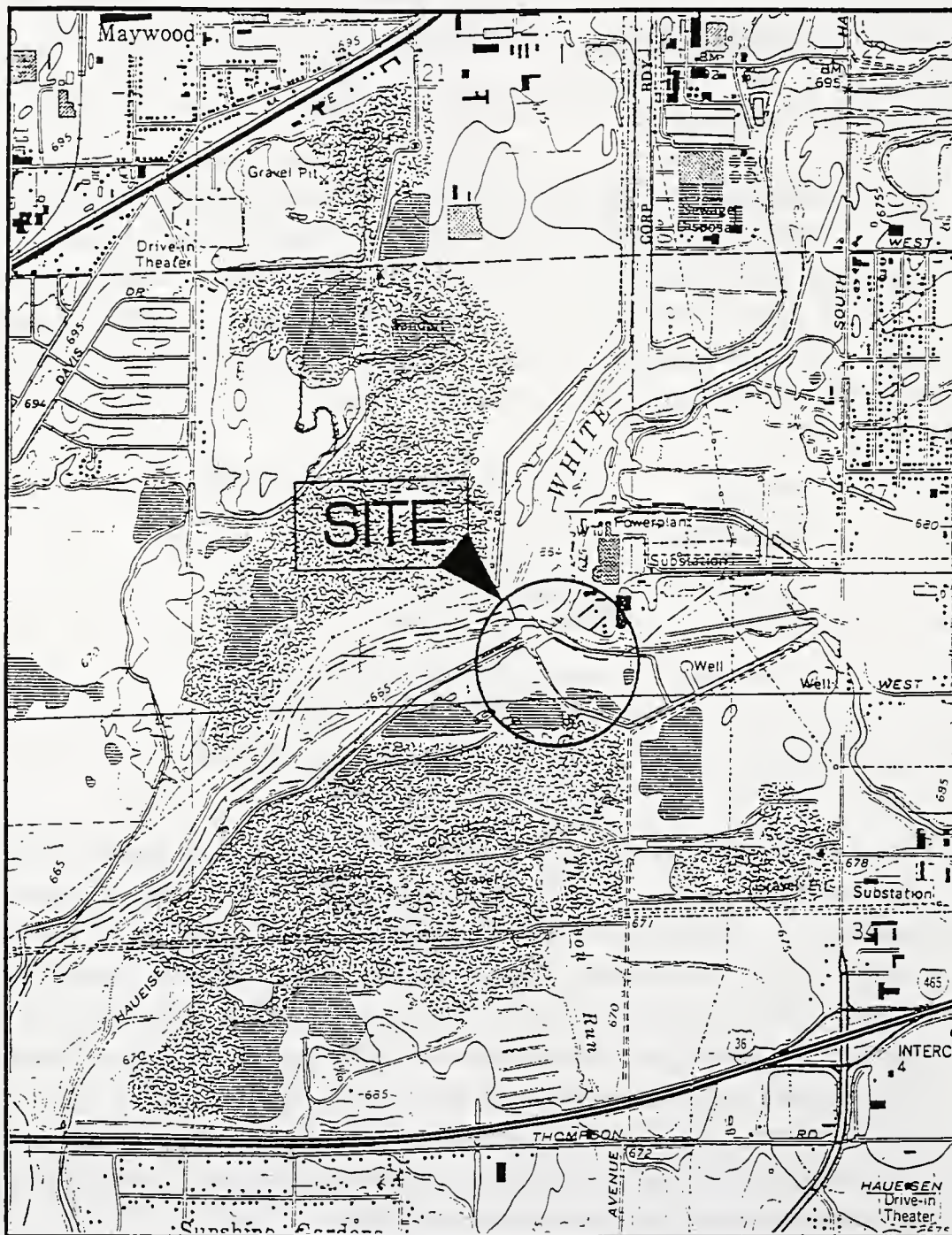
INTRODUCTION

In 1995, the Indiana Department of Transportation (INDOT) rebuilt the 56th Street overpass across I-465W in Indianapolis in order to improve vehicular access and safety. This construction project involved the renovation of two existing earth embankments, which were both widened using ponded coal combustion by-product (CCBP) ash (approx. 10,000 yd³ per embankment). The ash was obtained from Indianapolis Power & Light (IP&L) ash ponds at the E.W. Stout Generating Station in Indianapolis, as follows:

Ash Type:	Coal Combustion By-Product (CCBP)
Ash Generation:	E.W. Stout Generating Station Ash Pond No. 1 Indianapolis Power and Light (IP&L) Indianapolis, Indiana
Ash Source:	Adjacent to Test Pit Sites No. 1 and 2 (see Figures 1 and 2 ; re: TP-1 & 2)
Material Classification:	Indiana 'Environmental' Type III Material (i.e., see 329 IAC 2-9-3)

This report presents the results of a complementary engineering project which was completed to assess the environmental and geotechnical performance of these ash embankments. The environmental work focused on a characterization of well water samples obtained in the vicinity of this site before, during, and after construction. In addition, a number of *in-situ* lysimeter water samples were also procured and tested both during and after construction. In each case, these water samples were evaluated in terms of their constitutive metal concentrations, as well as their relative bioassay response (i.e., using a MicrotoxTM protocol). The geotechnical work included monitoring of ash water content and unit weight during placement, settlement analysis, and *in-situ* testing of the completed ash fills using the Standard Penetration Test.

Figures 3 and **4** depict representative plan and profile views of the project, respectively, with the latter schematic showing a cross-section of the western coal ash embankment. The coal ash was compacted with 5 passes of an Ingersol-Rand steel wheel (static) roller model SD-100-D. The thickness of the lifts was 0.20 m (8 in.) loose, and 0.15 m (6 in.) after



VICINITY MAP
 ASH POND No. 1
 IPL E.W. STOUT GENERATING STATION
 INDIANAPOLIS, INDIANA

Project Number:

21-07-94-00231

Scale:

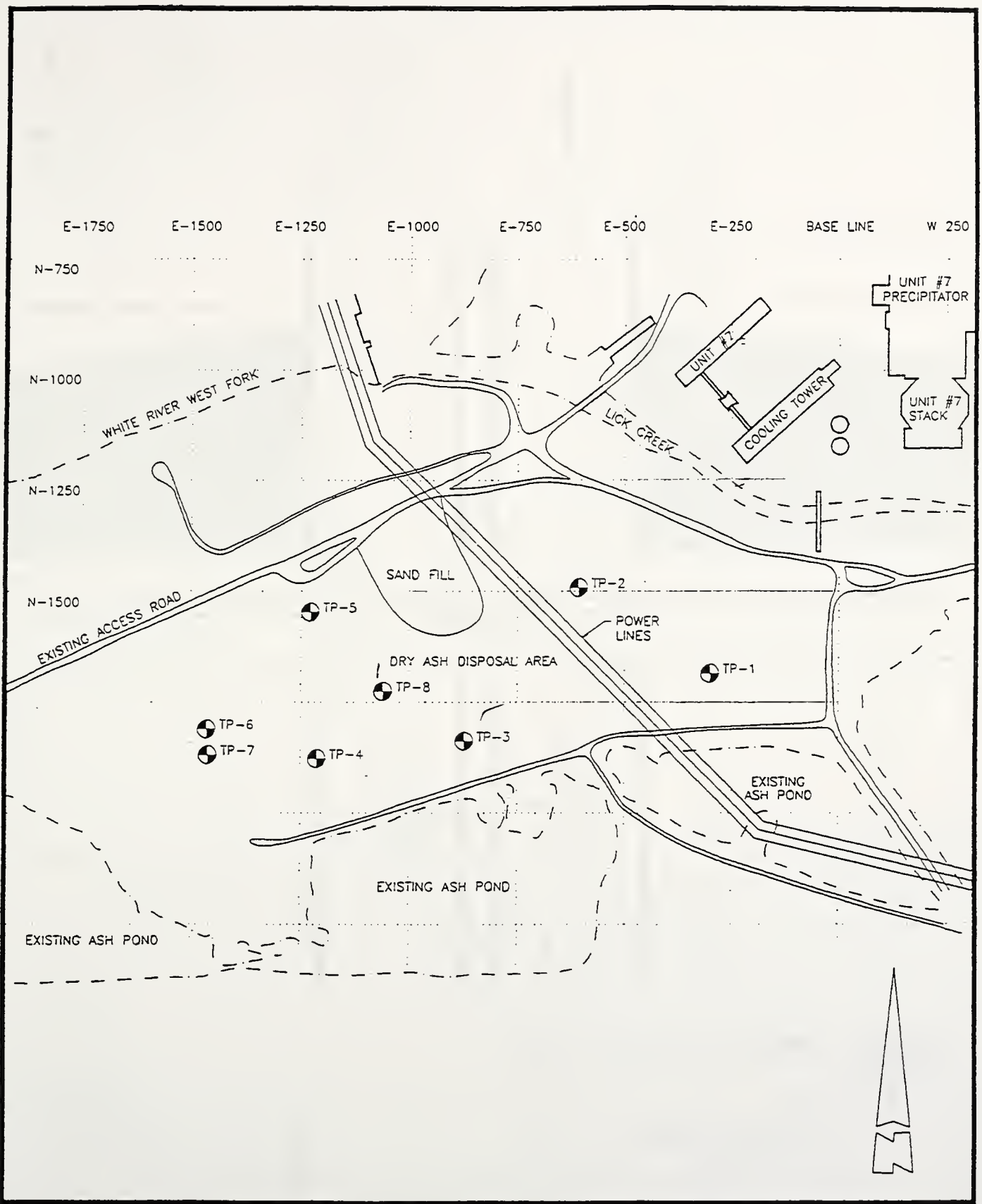
1" = 2000'

Figure Number:

1



1994



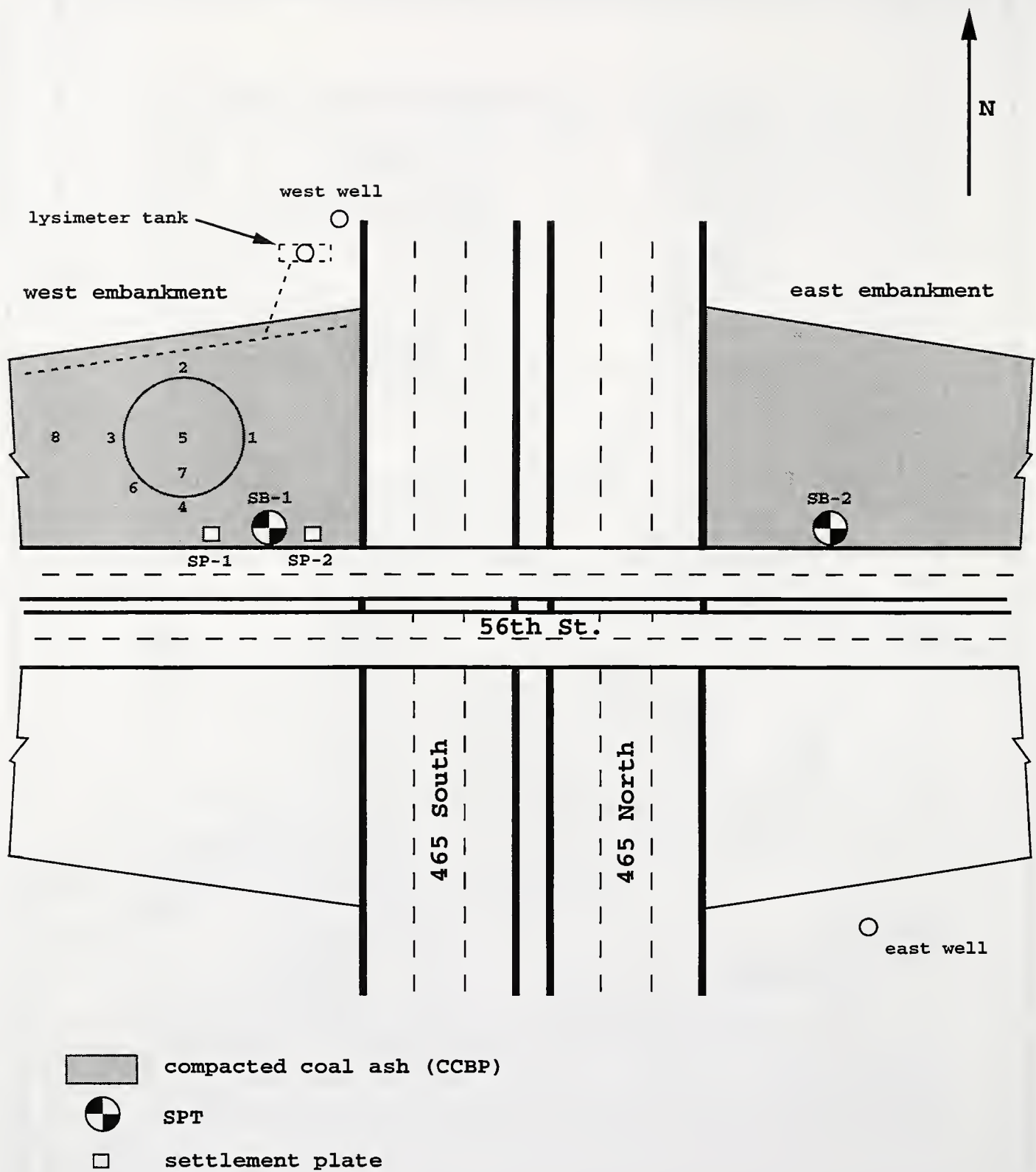
TEST PIT PLAN
 ASH POND No. 1
 IPL E.W. STOUT GENERATING STATION
 INDIANAPOLIS, INDIANA

Project Number:
 21-07-94-00231

Scale:
 1" = 300'

Figure Number:
 2





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Figure 3 - Plan View of 56th Street Overpass

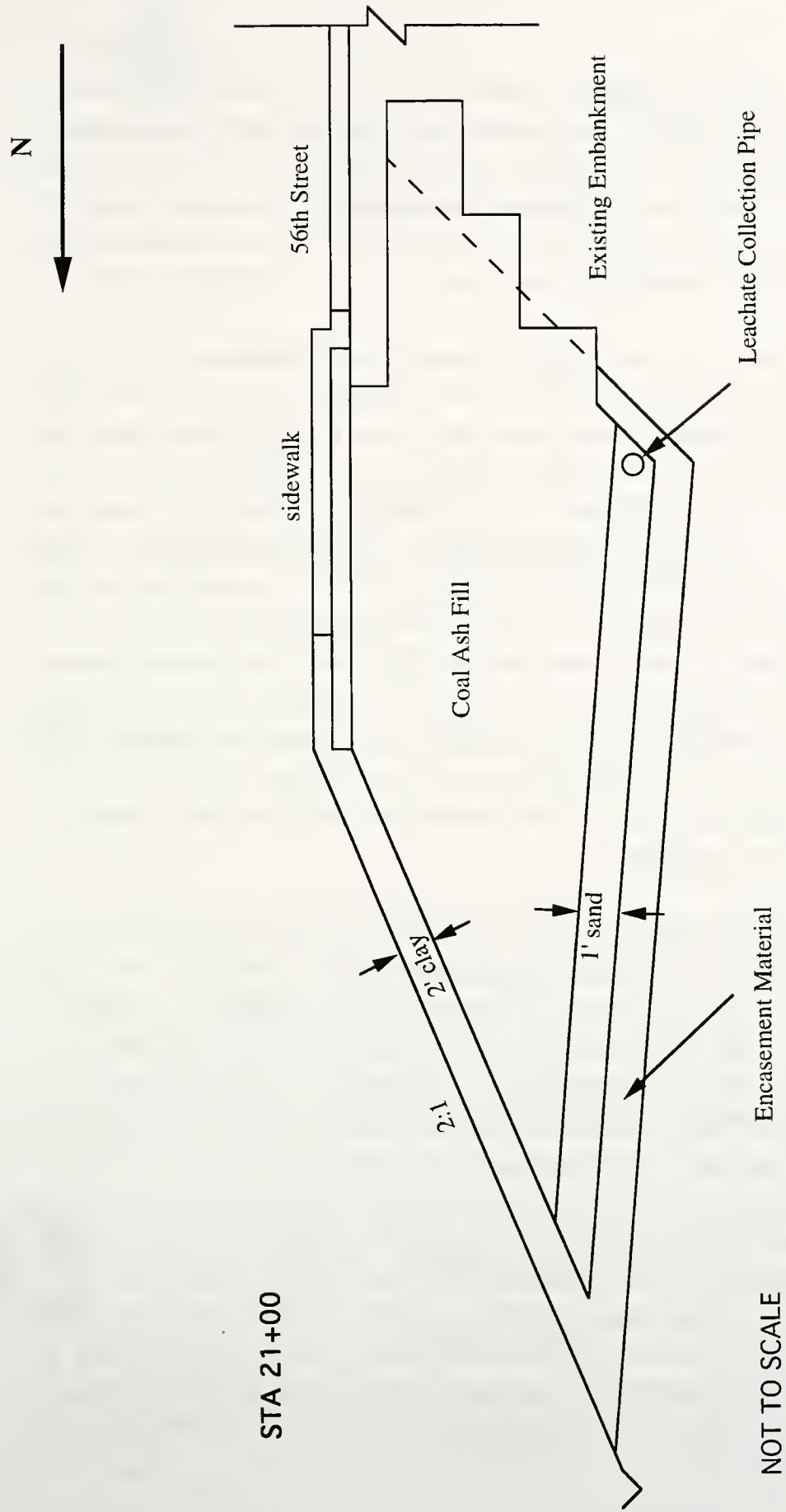


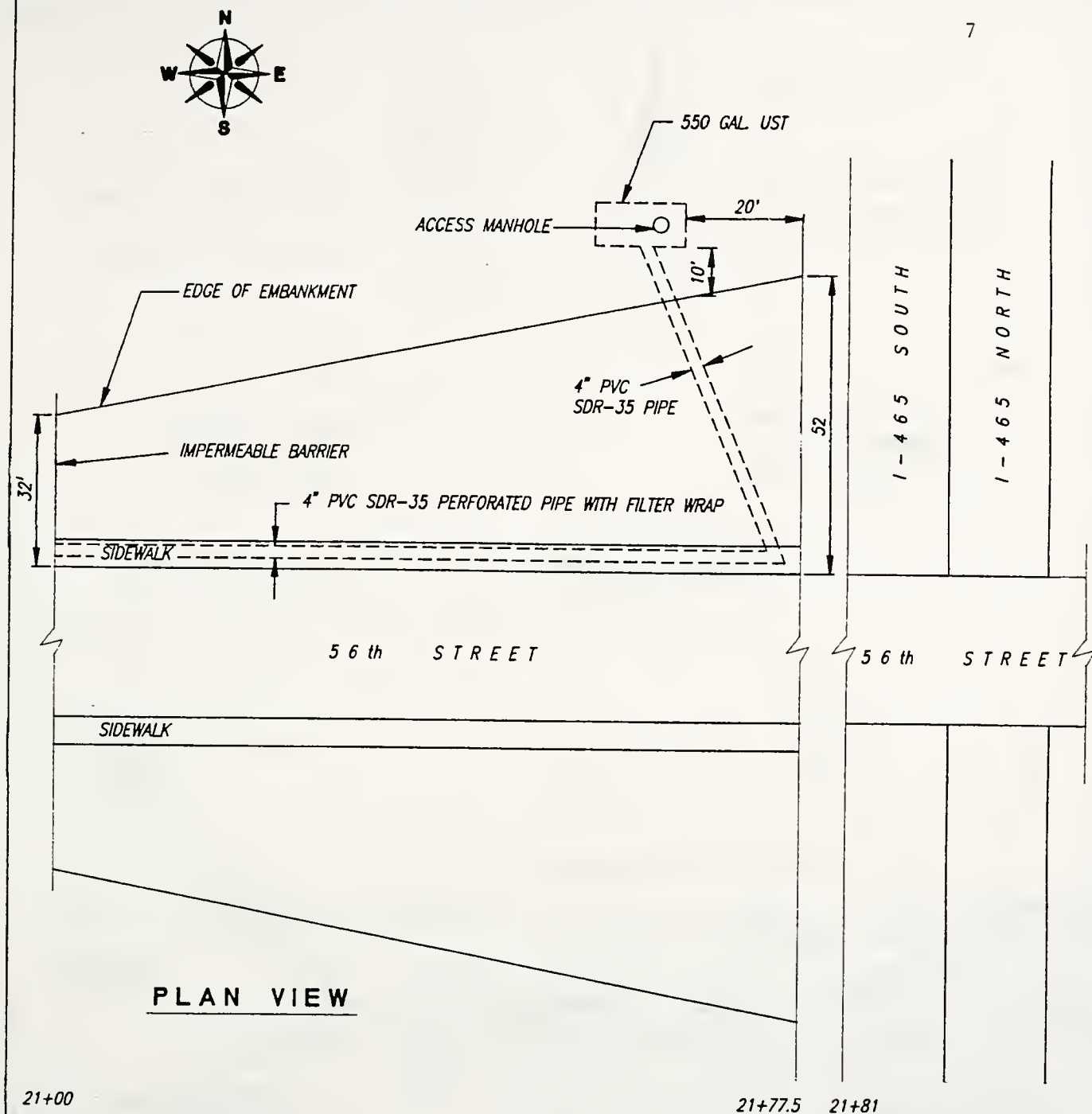
Figure 4 - Cross-Section of 56th Street West CCBP Embankment

compaction. The ash was compacted against the existing embankments composed of natural soils. Prior to placing the ash, benches were cut into the existing embankments to improve the stability of the ash fill. The coal ash was encased by 0.6 m (2 ft) of compacted clay on all sides except the south because of the difficulty of compaction against the benched cut slopes. The greatest thickness of the ash for the west embankment was approximately 5 m (16 ft) near the overpass bridge.

A leachate collection system was constructed under the west embankment to evaluate the quality of any water that passed through the coal ash. **Figure 5** depicts the plan view of this lysimeter and affiliated collection tank, while **Figures 6** and **7** depict the original profile view prepared by the responsible engineer (i.e., Matthew Rush, Keramida Environmental Inc.). The collection system was constructed by placing a 1 ft thick sand blanket above the bottom clay encasement along a 75 ft length of the embankment. The sand blanket was sloped at 2% to a 102 mm (4 in) PVC SDR-35 perforated pipe with filter wrap. This lysimeter collection pipe drained into a 550 gal underground storage tank, with its overflow allowed to simply percolate into the adjacent soil. The lysimeter collection tank was sampled throughout the course of the construction project, along with a similar set of chronological samples taken from two shallow groundwater wells installed in the immediate area. The locations of these two wells, shown in **Figure 1**, were as follows: 1) west well - situated due north of the west embankment, and 2) east well - situated due south of the eastern embankment.

Based on the existing topography and known directions of the local surface waters, it was believed that groundwater movement in the immediate vicinity of this project was passing from NW to SE, which would have brought the flow from the west to east wells. The west well was in close proximity to its respective CCBP material since the ash embankment was on the north side of the street. However, the east embankment was also constructed on the northern side of 56th street, such that the east well used for groundwater sampling was considerably further from the CCBP ash than the west well.

The investigators first visited the site on 24 April 1995, and the ash was subsequently placed over the next two months. Settlement plates were installed in early May, and fill settlement testing continued throughout the summer and fall. *In-situ* testing of both the east and west coal ash embankments was performed on 21 November 1995. Sampling and analysis of the two groundwater wells was initiated in April 1995, and lysimeter sampling and testing was started in June 1995 following the installation of the lysimeter.



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FIGURE 5

LEACHATE COLLECTION SYSTEM

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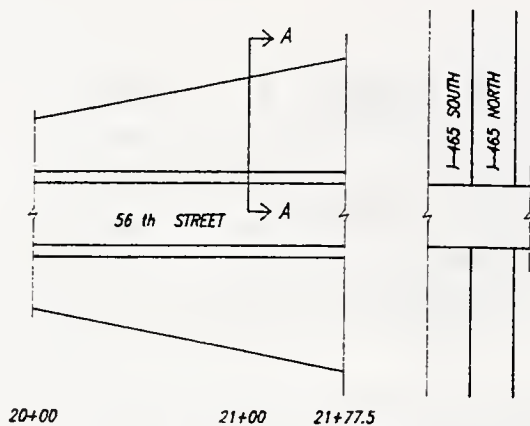
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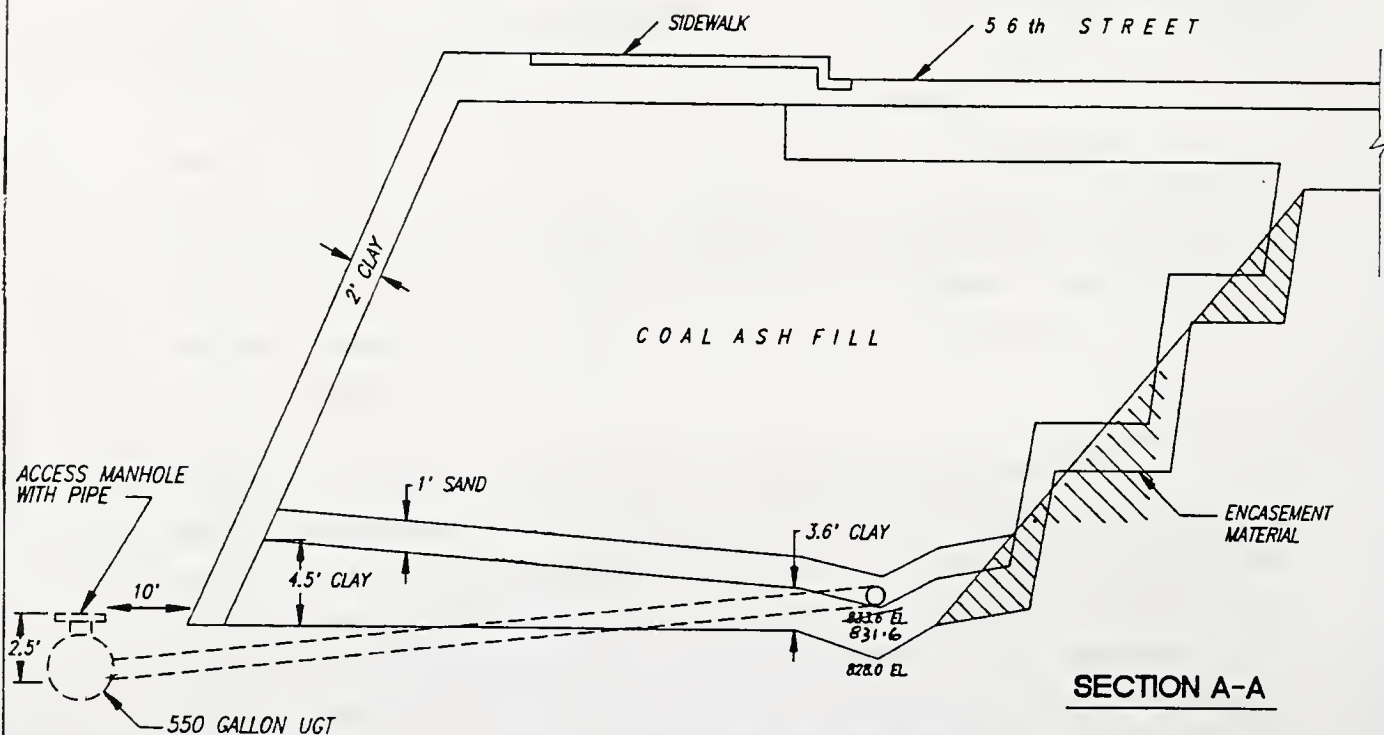
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PLAN VIEW

SHOWING SECTION A-A
UNDER SIDEWALK & STREET



SECTION A-A

FIGURE 6
LEACHATE
COLLECTION
SYSTEM



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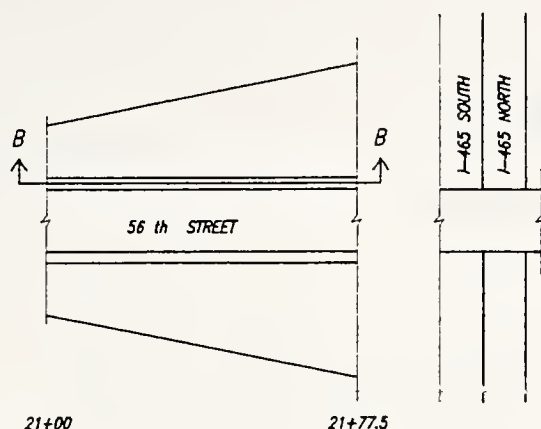
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Rev. Date : 9 - 15 - 94

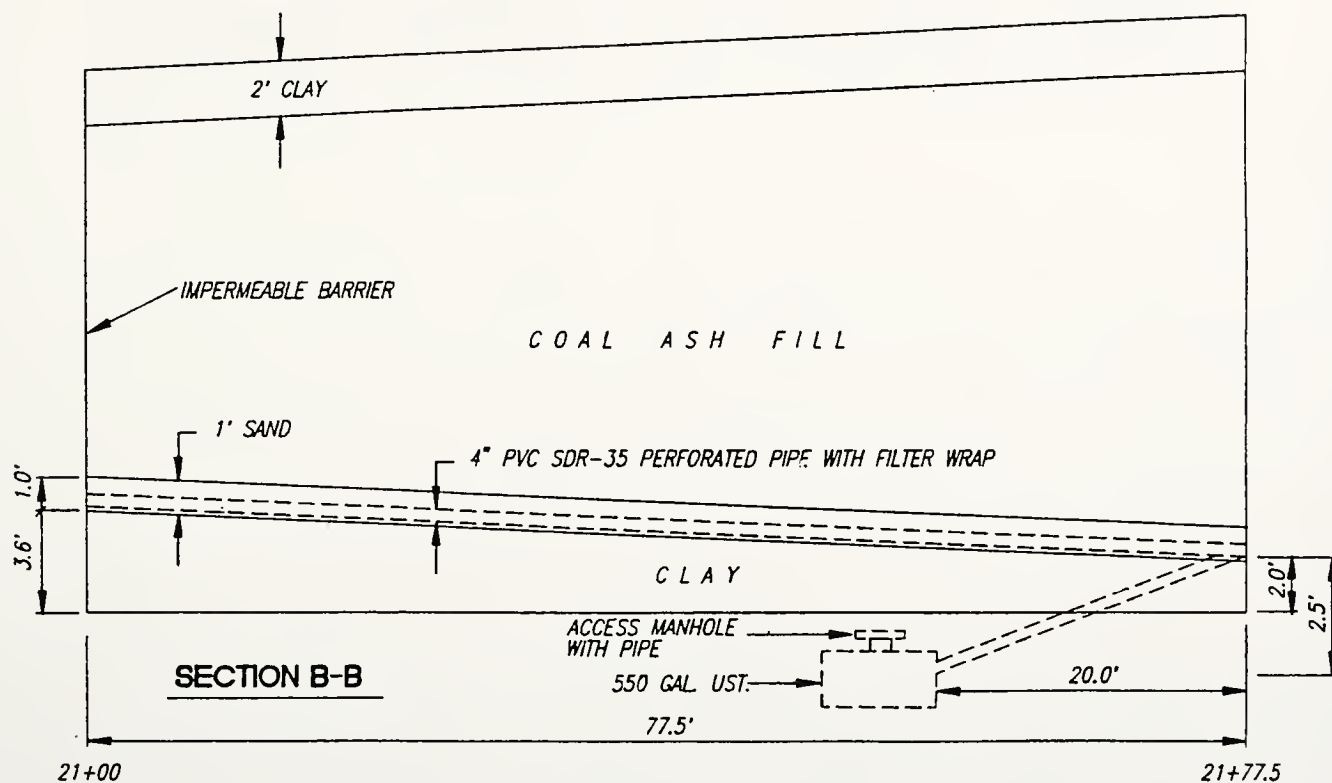
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PLAN VIEW

SHOWING SECTION B-B
UNDER SIDEWALK



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FIGURE 7

LEACHATE COLLECTION SYSTEM

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Date : SEPTEMBER 16, 1994
Rev. Date : 9 - 15 - 94
Scale : NOT TO SCALE
Project No. : 5523

CHAPTER 2

PROBLEM STATEMENT

The need for this research project stems from the general interest of INDOT in the recycling and reuse of waste materials for highway construction. Ash from coal-fired power plants has been identified as a possible candidate source material for the construction of highway embankments. The benefits of reusing CCBP for highway construction are: i) low-cost source material for INDOT, ii) reduced disposal costs for Indiana utilities, and iii) savings of Indiana landfill capacity. However, concerns exist regarding the environmental impact and geotechnical performance of the ash. Therefore, this study was funded by INDOT to provide information to guide the future construction of embankments using coal ash and similar waste products.

CHAPTER 3

OBJECTIVES

The overall objective of the project was to assess the environmental and geotechnical performance of two highway embankments widened using coal combustion fly ash. The following specific objectives guided the *environmental* and *geotechnical* aspects of the project:

- Environmental Objectives: i) to evaluate the extent of metals released from the employed coal ash, ii) to evaluate the extent of organics released from the employed coal ash, iii) to qualify the potential release of toxins from this coal ash, and iv) to determine whether the coal ash had any undue, negative environmental impact on monitoring wells in the immediate vicinity.
- Geotechnical Objectives: i) to develop correction factors for use with present methods of determining *in-situ* water content and unit weight, ii) to monitor settlement and compressibility of the coal ash embankment, and iii) to conduct Standard Penetration Tests after construction to measure ash strength and consistency with depth.

CHAPTER 4

WORK PLAN

4.1 ENVIRONMENTAL PLAN

4.1.1 Site Water Sampling

In order to check the background water quality prior to starting the project, water samples were collected from a pair of local groundwater monitoring wells which were installed before starting the placement of any coal combustion by-product. In addition, metals and bioassay tests were also completed on a sample taken from a nearby (and assumedly downstream) lake in order to provide a similar 'baseline' for its quality prior to the project. There were no subsequent samples taken from this lake, however, given the obvious lack of any significant contaminant release from the installed ash embankments. During embankment construction, the groundwater sampling events were then escalated in frequency. The collection of lysimeter samples was begun once the lysimeter had been installed. With this construction effort having now been completed, it should be noted that well and lysimeter samples will continue to be drawn and analyzed on a semi-annual to annual basis over the next four years in order to detect any long-term leachate problems.

4.1.2 Environmental Analyses and Methods

4.1.2.1 Chemical Oxygen Demand:

The chemical oxygen demand (COD) tests, which were completed at Purdue's School of Civil Engineering to quantify the possible presence of oxidizable organic contaminants, were conducted with a standard 'dichromate' digestion procedure using commercially-available, pre-packaged (i.e., HACH Company, Loveland, CO; Low-range 0-150 mg/L; Model 21258-25) colorimetric reaction tubes.

4.1.2.2 Metals:

All metal analyses completed on the obtained water samples were analyzed using an inductively coupled plasma (ICP) spectrophotometric procedure. These tests were determined on a contract-basis largely by Purdue University's Department of Food Science, although parallel samples were also sent on one occasion to Heritage

Environmental Services, Inc. (Indianapolis, Indiana) for quality control and analytical verification purposes. Twelve (12) metals were routinely analyzed, as follows:

Aluminum	Iron
Boron	Manganese
Cadmium	Molybdenum
Cobalt	Nickel
Copper	Lead
Chromium	Zinc

4.1.2.3 Microtox™ Bioassay:

Bioassay tests completed on the obtained water samples were conducted at Purdue's School of Civil Engineering using the commercially-available Microtox™ procedure. In each case, these tests were completed using a 'Basic' analytical comparison protocol for this test, in which a 'toxic' or 'non-toxic' response with each water sample is quantified relative to a standard 'control' water whose quality is known to be fully non-toxic (i.e., previously prepared as a synthetic water using salts bearing no measurable inhibitory impact). Two successive results are recorded with each such Microtox™ test, with measurements being respectively taken at elapsed times of 5- and 15-minutes. Potentially 'toxic' or inhibitory contaminants which demonstrate a response after only 5 minutes are typically the result of organic-type pollutants. On the other hand, samples which show a sizable increase in their level of response at the 15-minute time frame are usually attributed to metallic contaminants. As such, the fact that the Microtox™ tests completed during this study routinely showed little change from their 5- to 15-min. values strongly suggests that organics were the dominant factor in those cases where a negative response was observed.

4.2 GEOTECHNICAL PLAN

4.2.1 Compaction

Compaction is commonly used to improve the strength and reduce the compressibility of fills. The degree of compaction is assessed by comparing the dry unit weight of the soil in the field to a target value determined from laboratory compaction tests (e.g., Proctor tests). The water content of the compacted fill is also closely monitored in the field because of the strong influence of moisture on the compacted unit weight of many soils.

The most reliable methods to determine field water content and unit weight during construction are oven drying and the sand cone method, respectively. Although accurate, both of these methods are time-consuming. Thus, in practice, a number of alternative methods have been developed to reduce the time required to make these measurements. Water contents can be rapidly measured using the nuclear density gauge, Speedy Moisture Meter, and stove-top heating method. *In-situ* unit weights can be quickly measured using the nuclear gauge. Currently, little data exists regarding the accuracy of these rapid measurement techniques for compacted coal ash.

A study was performed to determine calibration factors for the nuclear density (Troxler) gauge for measurement of water content and dry unit weight of compacted coal ash. Coal ash contains material constituents (i.e., cadmium, hydrocarbons, unspent coal, shale) which may introduce measurement errors. Water content correction factors were also determined for the Speedy Moisture Meter and stove-top methods. Calibration factors were calculated by subtracting an average measured density or water content from the average true density or water content. The true value for density was determined from the sand cone method and the true water content was determined in the Purdue Bechtel Laboratory using a conventional 110° C oven (ASTM D2216-90). The calculated correction factors may then be used to adjust water content and unit weight measured in the field. A Standard Proctor compaction test (ASTM D698-91, Method B) was also performed on the IP&L CCBP for comparison with the unit weights measured in the field.

4.2.2 Unit Weight

Calibration factors for unit weight were found using a procedure described to the investigators by Robert Rahn of INDOT. Seven nuclear gauge tests and seven corresponding sand cone tests were performed around the circumference and at the center of a 10 ft diameter circle on the surface of the compacted coal ash. **Figure 3** shows the location of the circle and the individual density tests. The Troxler nuclear gauge was operated using the direct transmission mode rather than the backscatter mode to increase the volume of ash tested for each measurement. All offsets and calibration factors for the nuclear gauge were disabled prior to testing, and all readings were taken using the standard “1 minute” count. A total unit weight measurement was discarded if it deviated by more than 1.5 pcf from the mean unit weight of the previously obtained values. In such cases, an additional test was performed at another location on the circle. A corresponding sand cone test was performed in the immediate vicinity of each nuclear gauge test. The high and

low values of total unit weight (from the nuclear gauge) were discarded, leaving five remaining values. The unit weight calibration factor was then calculated by subtracting the average of five nuclear gauge total unit weights from the average total unit weight from the sand cone tests. Four additional pairs of nuclear density and sand cone tests were subsequently conducted at random to assess the correctness of the calculated unit weight calibration factors.

4.2.3 Water Content

Water content correction factors were determined similarly to the unit weight correction factors. For the same five tests on the test circle, water contents were calculated using the Speedy Moisture Meter, stove top, nuclear gauge, and laboratory oven-drying methods. Correction factors were determined by subtracting the average water content obtained from each of these methods from the average water content obtained from the laboratory oven.

The nuclear gauge measures the total unit weight of the ash, γ , and weight of water, W_w , per unit volume of ash. The water content, $w\%$, may be calculated from γ , as follows:

$$w\% = \frac{W_w}{\gamma_d} \times 100 \quad (1)$$

where, W_w = weight of water per unit volume of ash (pcf)
 $\gamma_d = \gamma - W_w$ (pcf) = dry unit weight of ash

4.2.4 Settlement

Settlement of the west coal ash embankment was monitored using two settlement plates placed on top of the lower compacted clay encasement. The plates were installed on 3 May 1995. Plate No.1 is located at Station 20+50 and Plate No. 2 at Station 20+85 (**Figure 3**). Settlement of the fill was monitored by periodic surveys of the elevation of vertical riser pipes connected to the settlement plates. Additional details on settlement plate construction and installation may be found in "INDOT Specifications Field Manual," Section 204.03, Construction Requirements. The settlement plates give the total settlement of the fill due to the compressibility of the underlying foundation soils. Elevations of the fill ground surface were surveyed concurrently with the settlement plates. Construction of

the fill was completed on 14 July 1995. Surface elevation measurements were taken after construction to provide an indication of the compression of the ash fill itself over time.

4.2.5 *In-Situ* Testing

One Standard Penetration Test (SPT) was performed for each of the east and west embankments on 21 November 1995 (**Figure 3**). Continuous measurements of SPT blow count, N , were taken from the surface to the bottom of the compacted coal ash. The borehole for the west embankment (SB-1) extended to a depth of 4.9 m at STA 20+67. For the east embankment, the borehole (SB-2) extended to a depth of 5.8 m at STA 25+66. Water content samples were also taken as a function of depth from each borehole. The water contents were measured using the standard laboratory oven-drying procedure.

CHAPTER 5

ANALYSIS OF DATA

5.1 ENVIRONMENTAL ANALYSIS

5.1.1 Chemical Oxygen Demand

The COD tests conducted with samples taken from either well on 27 April 1995, prior to starting the placement of the ash, both showed results of approximately 1-2 mg/L. This concentration level is, admittedly, at the lower end of the test's relative sensitivity (i.e., using the pre-packaged, low-range HACH COD tubes), but it would appear that there may have been some type of low-level organic presence within these wells prior to starting the project.

However, three months later (18 July 1995) these values had dropped to a level below detection in both wells, which suggests that the original 'contaminants' had possibly been created by the process of installing the wells themselves. In retrospect, this material may have been introduced to these waters as either a residual adhesive used with the piping or as a plasticizer (e.g., phthalates) being released from the pipe matrix itself....which then 'flushed' out of the well water over time. COD tests conducted on both wells on 1 September 1995 were similarly low, to the point where subsequent testing was discontinued.

Two COD tests were completed on leachate samples obtained at this site (18 July 1995 and 1 September 1995) but neither of these samples showed a detectable COD presence. No COD tests were run on the 'lake' waters given the low values observed in the wells and lysimeter.

5.1.2 Metals

Only one sample from the nearby lake (i.e., east-southeast of the project site), taken on 27 April 1995, was tested for its constitutive metal content. None of these results showed any indication of unacceptable metal contamination. Subsequent efforts to collect and analyze further lake samples for their metal content were also abandoned given the low metal levels observed within the monitoring wells and lysimeter, as described within the following sections.

A chronological summary of the respective metal levels observed in the two wells and lysimeter is provided in Appendix A. The following discussion details the specific observations made for each of the twelve tested metal species.

Aluminum (*see Figure 8*)

The west well and lysimeter sites have yielded the highest aluminum levels to this point, with respective extremes of 0.52 and 0.12 being observed with their 18 July and 27 July 1995 samplings. These 'highs' subsequently dropped at both locations over the following months, to a point where all three sites have aluminum levels of (~ 0.1 mg/L or lower). These concentrations are within a typical, and certainly acceptable, range for groundwater samples. In retrospect, there was little indication that the CCBP had created any sort of detrimental impact on the adjacent groundwater in terms of an aluminum release.

Boron (*see Figure 9*)

The observed pattern of boron presence at the three immediate testing sites was analogous to that detected with aluminum, with the west well and lysimeter samples showing the highest concentrations. This metal's levels were, however, much higher than the other contaminants detected near this site, at concentrations ten or more times greater than any other metal. The lysimeter samples through March 1996 were rather constant, with values typically ranging from 7 to 9 mg/L. As for the west well samples, they exhibited a progressive increase from May 1995 (~ 0.2 mg/L) through mid-December 1995, at which point they leveled out at about the same concentration as has been found with the lysimeter samples (e.g., (~ 9 mg/L). However, this trend showed a significant, and downward, change as of the sample taken on 5 March 1996, at which time the boron concentration dropped to only 0.85 mg/L. Meanwhile, the east well boron levels remained consistently low, in the range of 0.1 mg/L. Overall, the CCBP did seem to be having an effect on the west well's groundwater boron level, but still well below the concentration limit (i.e., 20 mg/L) established for this material's Type III classification.

However, the most recent set of samples (west well and lysimeter), taken on 5 September 1996, has continued to show elevated levels of boron at both locations, with respective concentrations of 8.74 and 13.05 mg/L. The latter (i.e., elevated) level in the west well sample was consequently much higher than the value observed on 5 March 1996 (0.85 mg/L), suggesting that the lysimeter's adjacent discharge was again affecting this well.

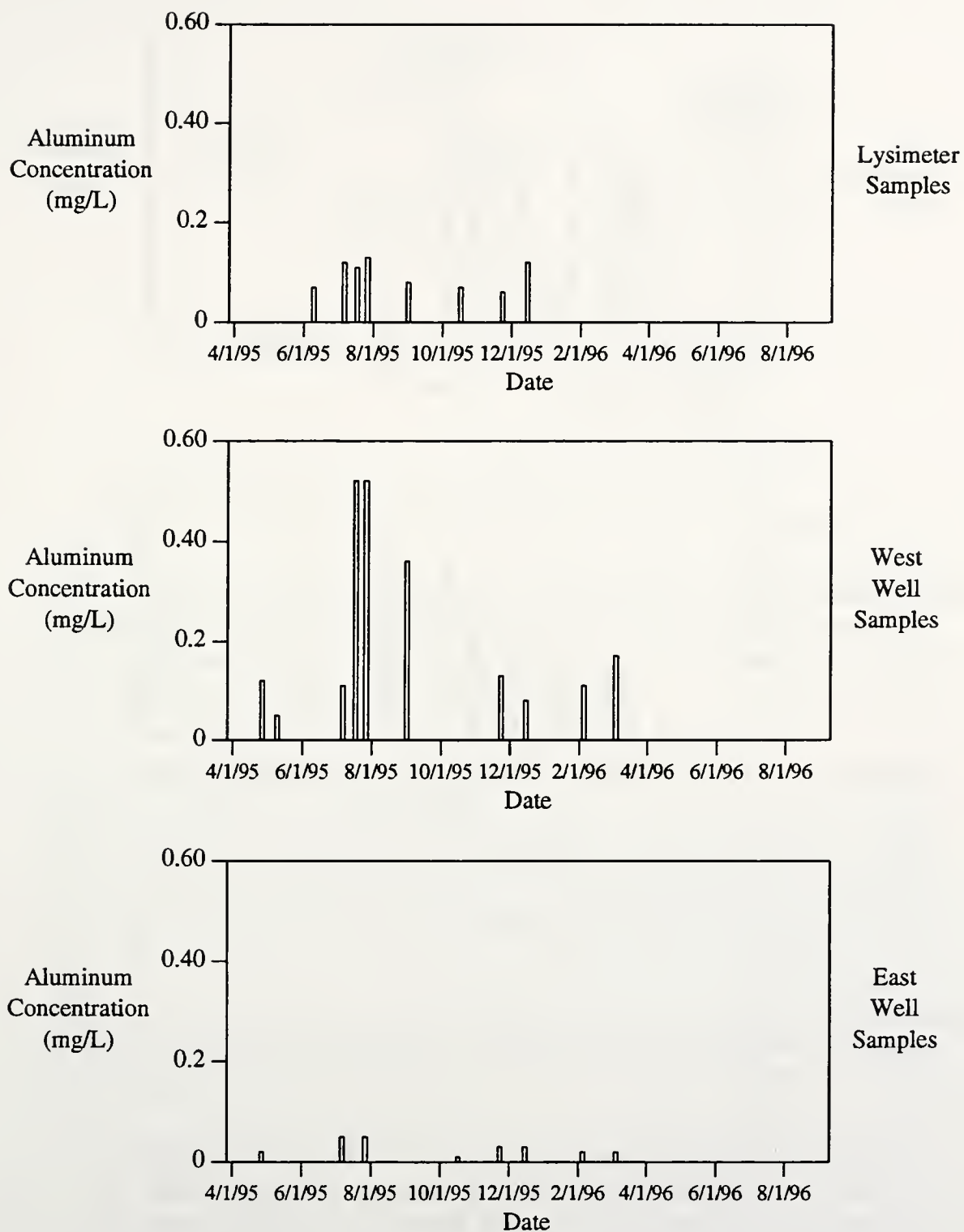


Figure 8. Aluminum Concentrations in Well and Lysimeter Samples

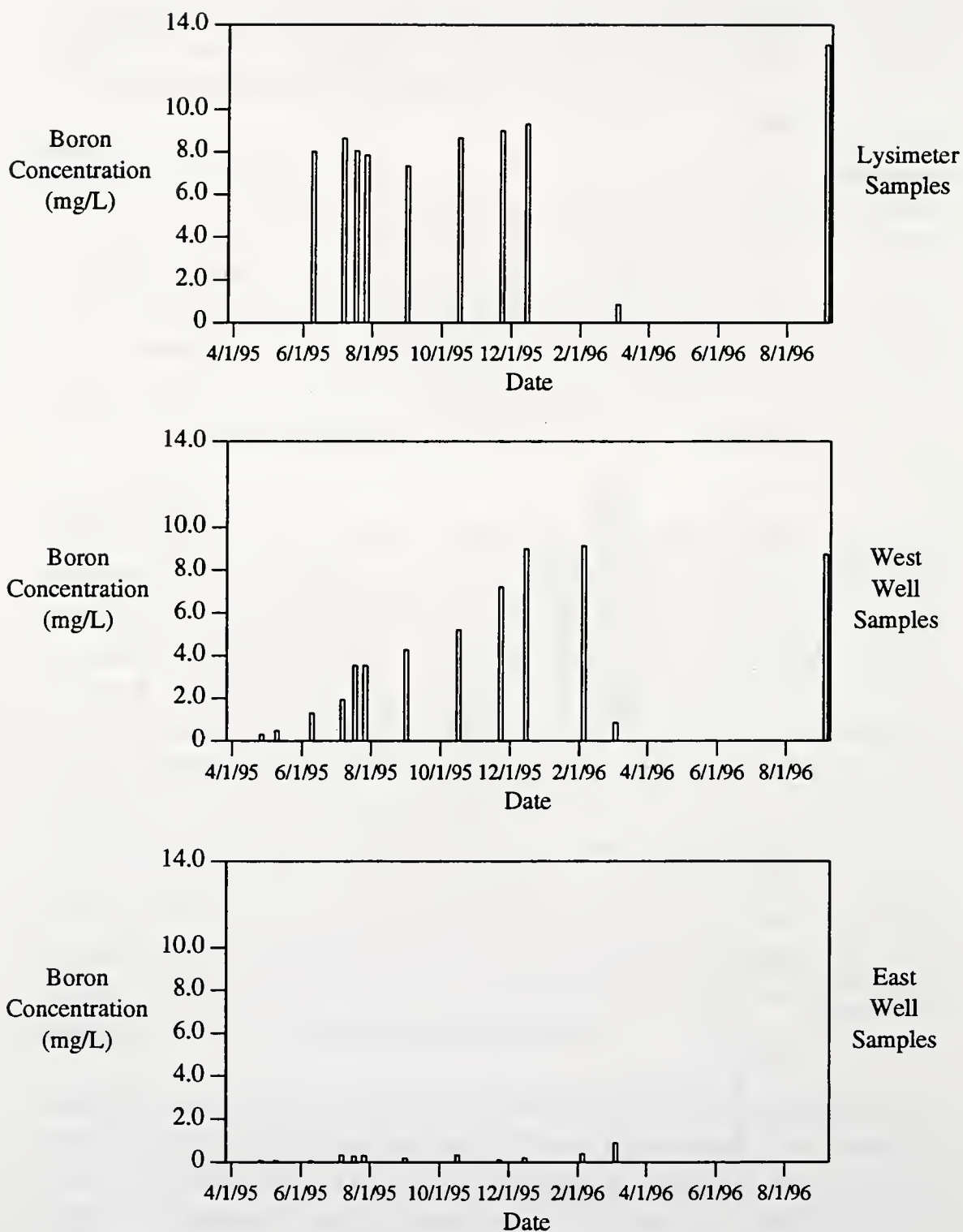


Figure 9. Boron Concentrations in Well and Lysimeter Samples

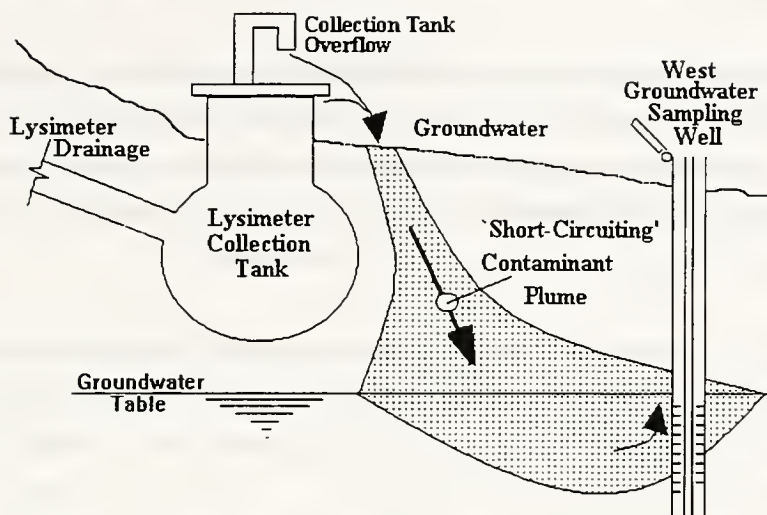


Figure 10: Schematic Profile View of Lysimeter Overflow 'Short-Circuiting'

When taking this latter group of samples, the lysimeter collection tank did not actually exhibit an ongoing discharge. The release of this water would be expected to intermittently stop when the static head within the lysimeter fell below the overflow line's (i.e., situated on top of the lysimeter collection tank) point of discharge.

However, after removing this tank's overflow line (see **Figure 10**), drainage immediately began leaving the tank and continued during the entire period of sampling (i.e., covering ~20-30 minutes, and releasing an estimated quantity of 200 to 400 gallons). Rather obviously, drainage from this lysimeter system was still being released, thereby causing the west well's boron level to return to the elevated levels observed at this location prior to March 1996.

In retrospect, several related comments are warranted in regard to this observed release of boron from coal ash used at the 56th Street site:

- 1) The presence of leachable boron within this coal ash likely stems from the fact that our eastern coals, and their corresponding ash residues, bear considerably higher levels of boron. For example, Hanson and Schumacher (1982) analyzed the total metals content of western *versus* eastern coal ash

residuals and found that their respective boron levels were 0.215 and 48.7 mg boron per kilogram.

2) The release of boron from coal ash disposal sites has been documented in the literature, and at concentrations comparable to the levels observed at the 56th Street location. For example, Morgan *et al.* (1982) and Theis *et al.* (1988) respectively observed elevated boron levels in pond (4.5 mg/L) and lysimeter (6.7 mg/L) waters taken from similar coal ash disposal sites.

3) The source of this boron largely appears to be the fly ash fraction of the coal ash residual. The results observed with four separate bottom ash leachates, as reported in the GAI Consultants Inc. (1993) report, show a range of boron concentrations from just 0.02 to 0.47 mg/L.

The general circumstance of boron being released by this emplaced coal ash into an underdrain lysimeter discharge, though, does not warrant any related concern about a 'human health' impact, at least in the range of observed boron concentrations; there is no regulatory limit for boron as either a primary or secondary drinking water parameter. Furthermore, even the highest boron levels measured at this site are still well below Indiana's Type III restricted waste citing criteria for this element (i.e., 20 mg/L).

On the other hand, the boron concentrations observed in the 56th Street lysimeter discharge are sufficiently high to create stress for a number of plant forms which might well be expected to grow within Indiana farmland areas immediately adjacent to these construction sites. For example, corn, peas, and sweet potatoes may show injury at 5 ppm boron levels, and potatoes, lima beans, and Kentucky bluegrass are even more sensitive with injuries expected at concentrations as low as 1 ppm (Sprague, 1972).

Ironically, many of these same plants actually need boron as an essential growth element, and at levels which are rather close to the injury threshold (e.g., with 1 ppm being required *versus* 5 ppm being inhibitory for corn). Furthermore, little is known regarding the short-*versus* long-term impacts associated with elevated boron exposure for plants.

As a result, this issue warrants further close observation during future CCBP embankment projects. Ideally, this sort of boron-rich interstitial embankment water would be released

either in an area away from sensitive plants or in a fashion amenable to its rapid subsurface migration away from the root zone.

The fact that boron is an anion will also be helpful, in that it should rapidly move through the soil column and away from the zone of influence on crop or plant root systems. Most other metals are positive or cationically charged contaminants, such that they actually tend to bind to soils and be retained rather than remain in a mobile (i.e., soluble) phase.

Cadmium (see *Figure 11*)

The observed results for cadmium have essentially been nil throughout the duration of this site's monitoring effort.

Cobalt (see *Figure 12*)

The observed results for cobalt have essentially been nil throughout the duration of this site's monitoring effort.

Copper (see *Figure 13*)

The observed results for copper have essentially been nil throughout the duration of this site's monitoring effort.

Chromium (see *Figure 14*)

The observed results for chromium have essentially been nil throughout the duration of this site's monitoring effort.

Iron (see *Figure 15*)

Although the lysimeter samples showed the highest iron levels, approaching 0.6 mg/L, all three sites had comparable concentrations of this particular metal. Conceivably, though, the higher iron levels at the lysimeter sites could be the result of external iron introduced not by the CCBP but rather corrosion taking place either within the lysimeter collection tank or on the surface of its bolted cover. Indeed, suspended rust particulates were routinely observed within the lysimeter samples. Here again, though, the measured iron levels were well within an acceptable range.

Manganese (see *Figure 16*)

As compared to the other tested metals, where the lysimeter and west well had the highest concentrations, the east well manganese concentrations were distinctly higher (reaching a

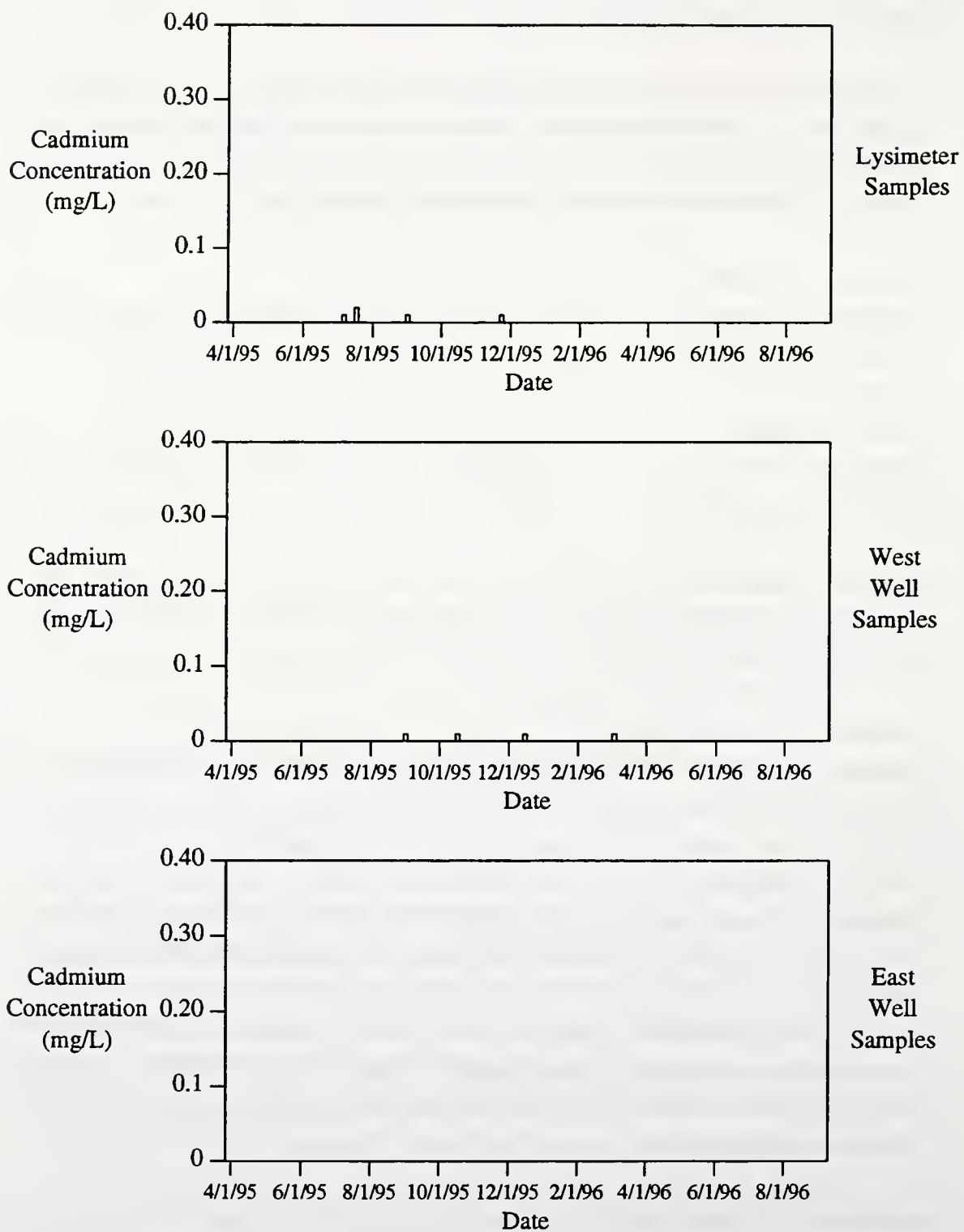


Figure 11. Cadmium Concentrations in Well and Lysimeter Samples

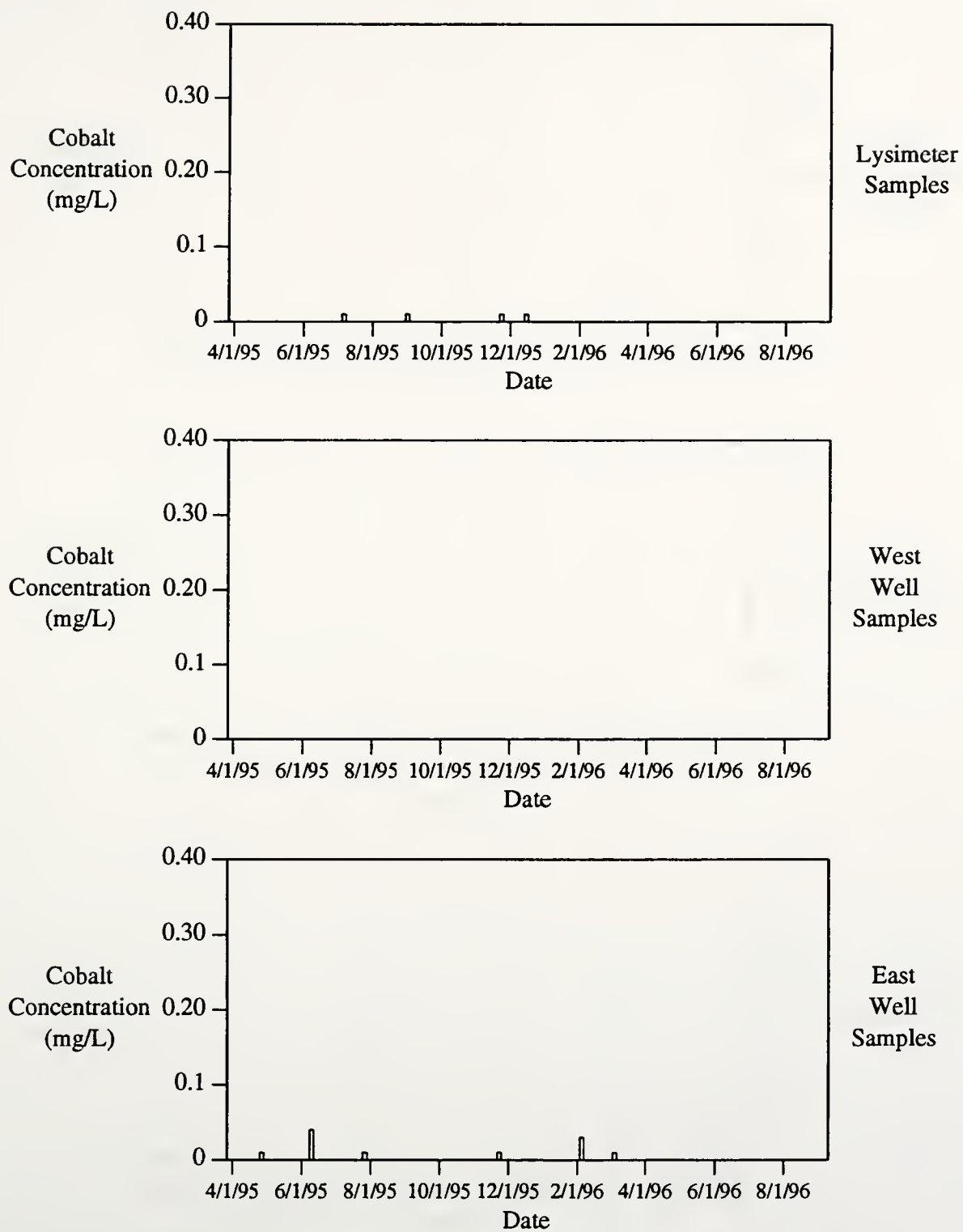


Figure 12. Cobalt Concentrations in Well and Lysimeter Samples

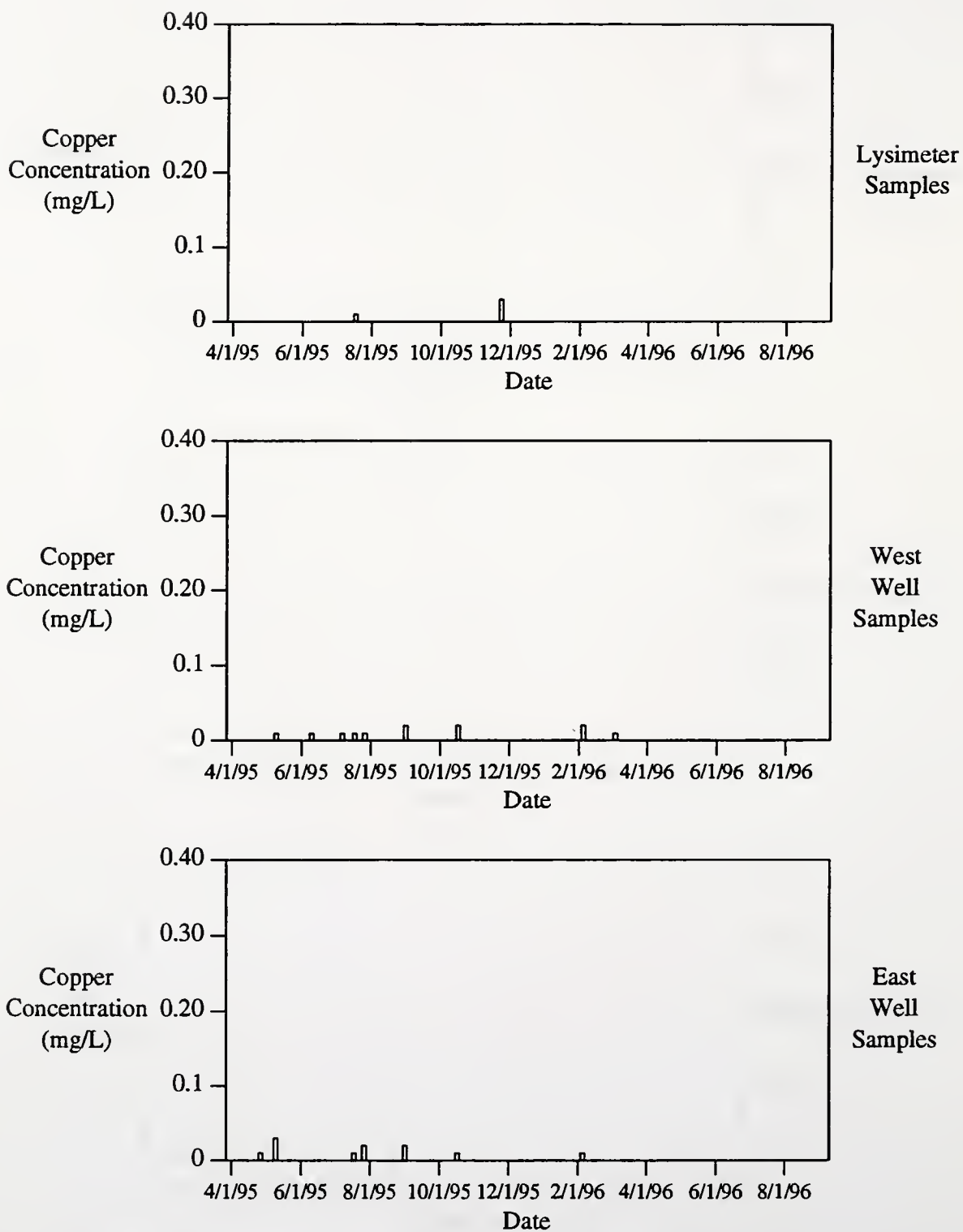


Figure 13. Copper Concentrations in Well and Lysimeter Samples

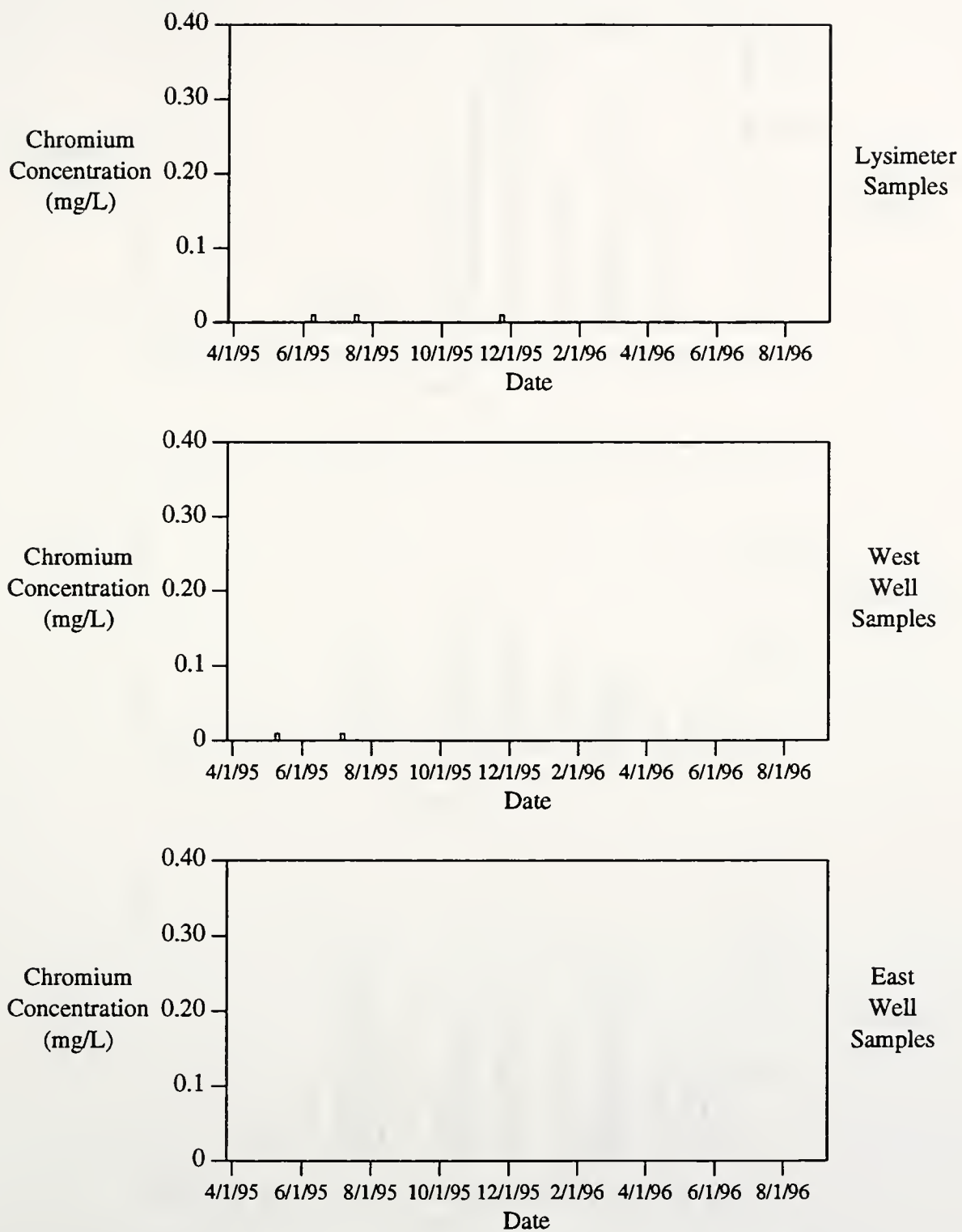


Figure 14. Chromium Concentrations in Well and Lysimeter Samples

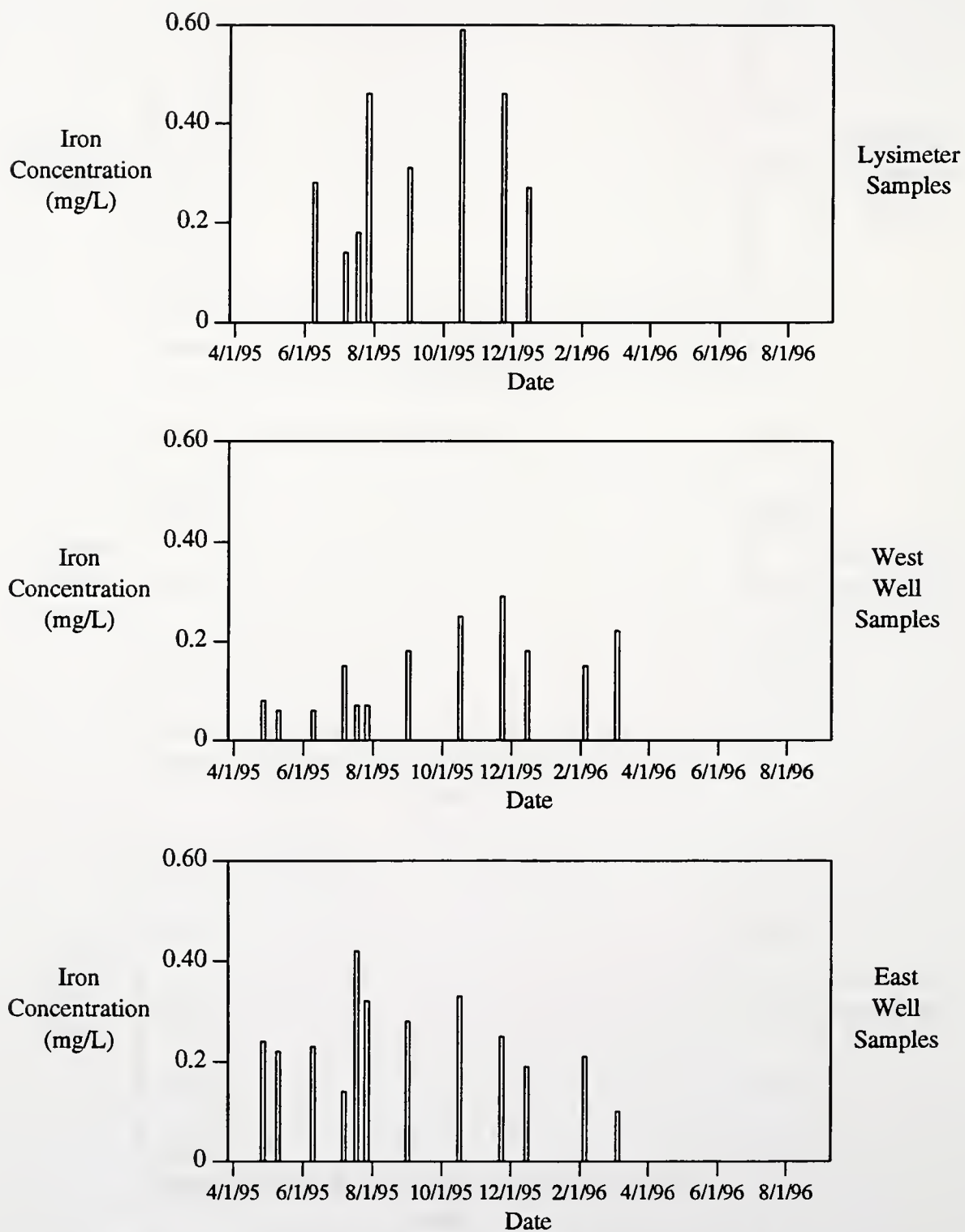


Figure 15. Iron Concentrations in Well and Lysimeter Samples

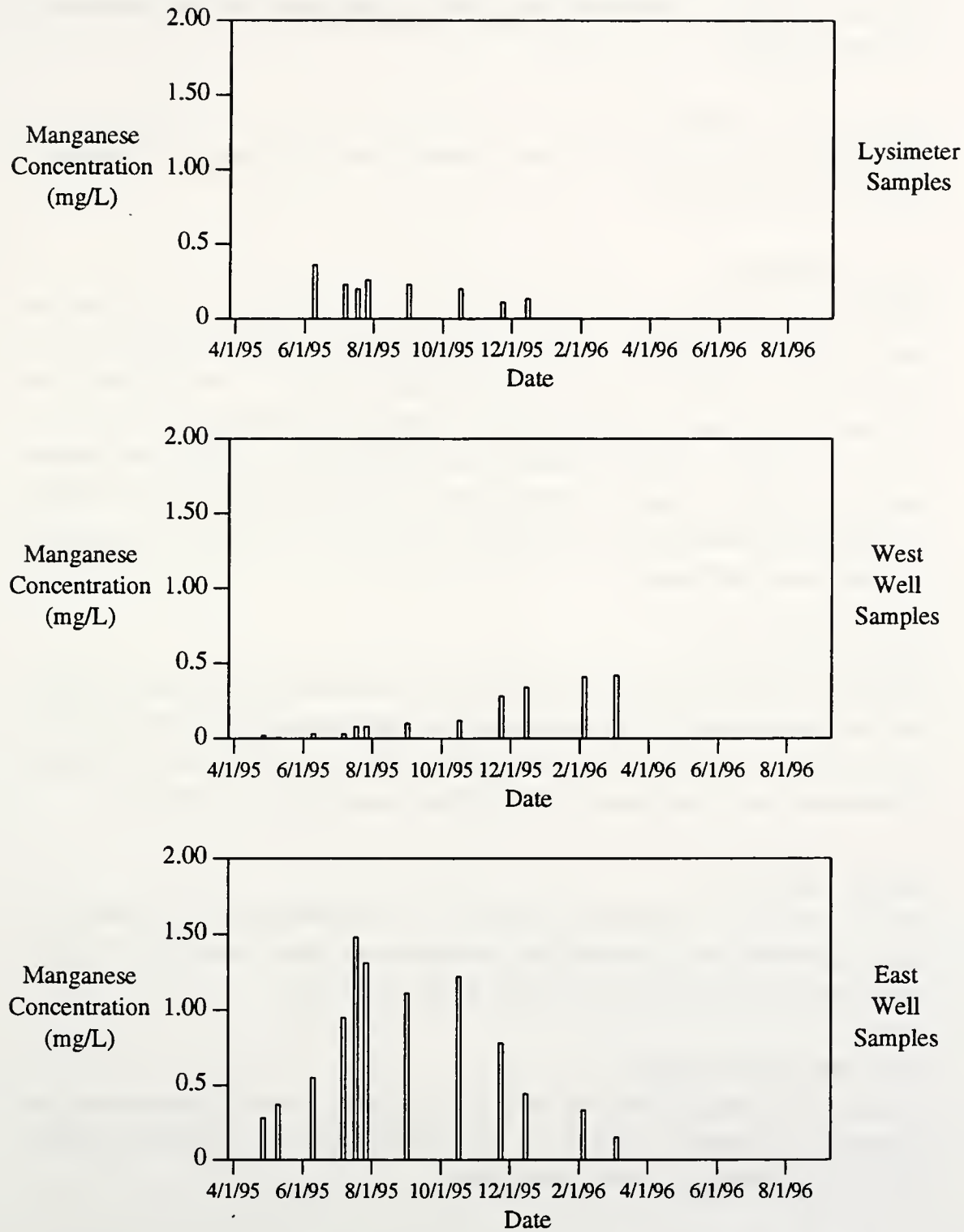


Figure 16. Manganese Concentrations in Well and Lysimeter Samples

peak of (~ 1.5 mg/L) but still well within an acceptable range for this element. Rather obviously, there was no indication that the CCBP had unduly created any undue risk due to manganese emission.

Molybdenum (see *Figure 17*)

The observed results for molybdenum have essentially been nil throughout the duration of this site's monitoring effort.

Nickel (see *Figure 18*)

The lysimeter nickel levels were distinctly higher than the values observed with either the west or east well, averaging 0.1 to nearly 0.2 mg/L. However, these concentrations were still well below the Type III limit, and actually closer to Type IV. As compared to the observation that anionic boron appeared to be migrating from the lysimeter overflow into the west well, this trend was not consistent with nickel. In this case, although the lysimeter overflow did contain a higher level of this metal, it appeared likely that cationic exchange was trapping this nickel within the soil such that it was not seen in the adjacent west well as had been the case with boron.

Lead (see *Figure 19*)

Here again, as with nickel, the lysimeter lead levels were distinctly higher than the values observed with either well. The observed trend was that of a nominal buildup through the summer, followed by a decline to a present level of nearly zero. Once again, though, these concentrations are still well below the Type III limit, and actually closer to Type IV.

Zinc (see *Figure 20*)

The zinc results were comparable to those of iron, with similar values being found at all three local sampling sites. There does not appear to be any distinct pattern to the observed concentrations, with an overall median value of about 0.25 mg/L.

5.1.3 Microtox™ Bioassay

A chronological summary of the respective Microtox™ levels observed in the two wells and lysimeter is provided in Appendix B. The following discussion details the specific observations made for each of the sampled sites.

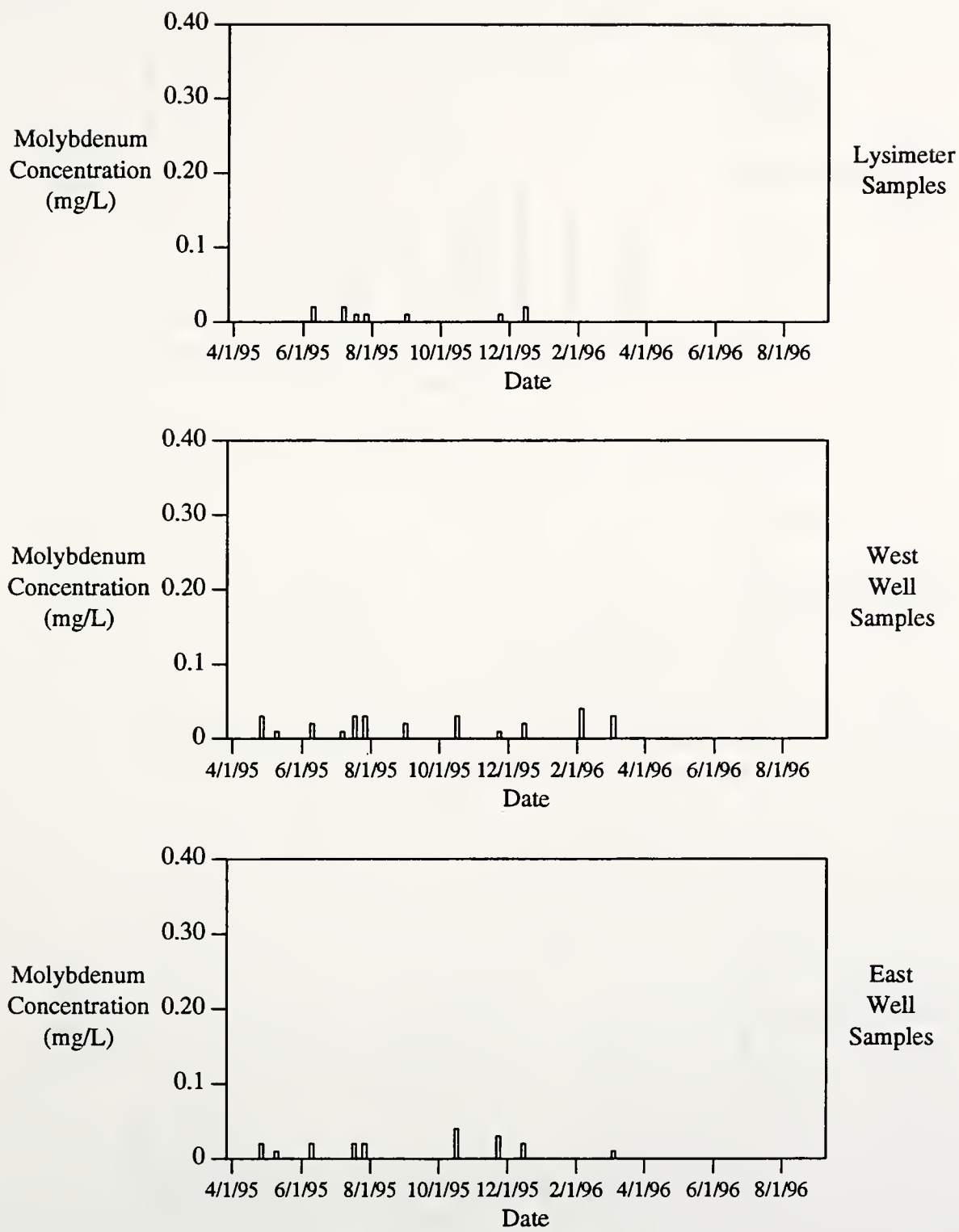


Figure 17. Molybdenum Concentrations in Well and Lysimeter Samples

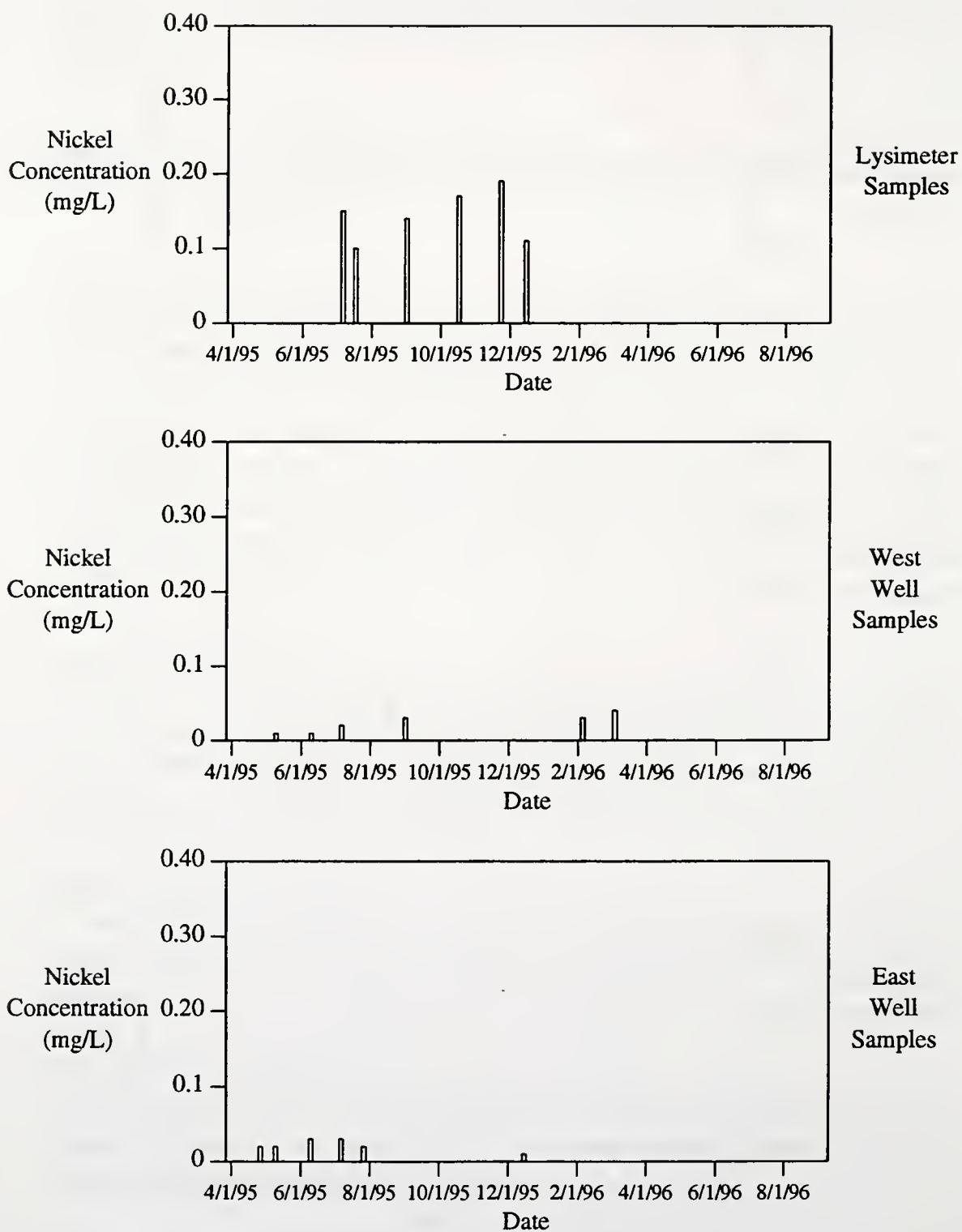


Figure 18. Nickel Concentrations in Well and Lysimeter Samples

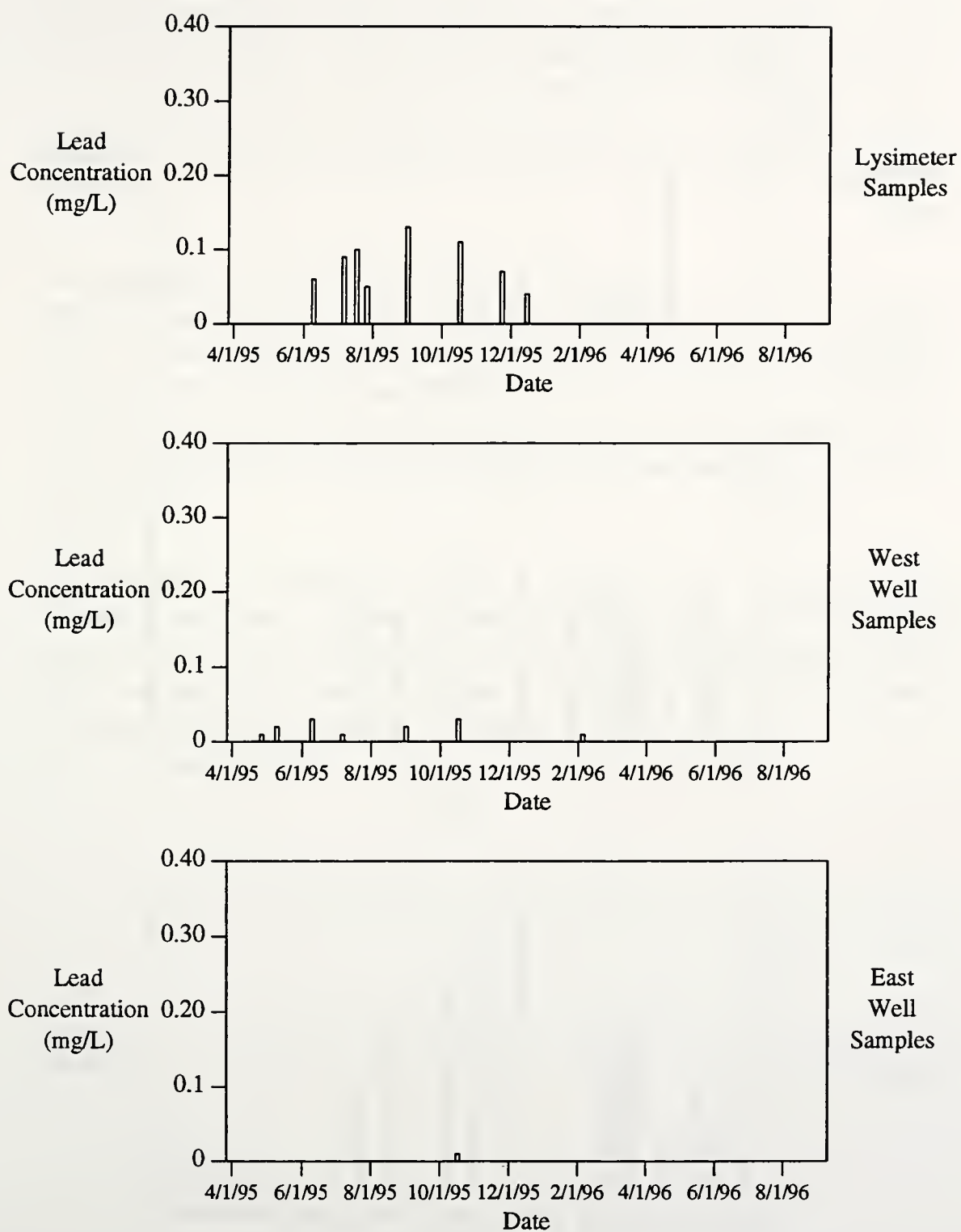


Figure 19. Lead Concentrations in Well and Lysimeter Samples

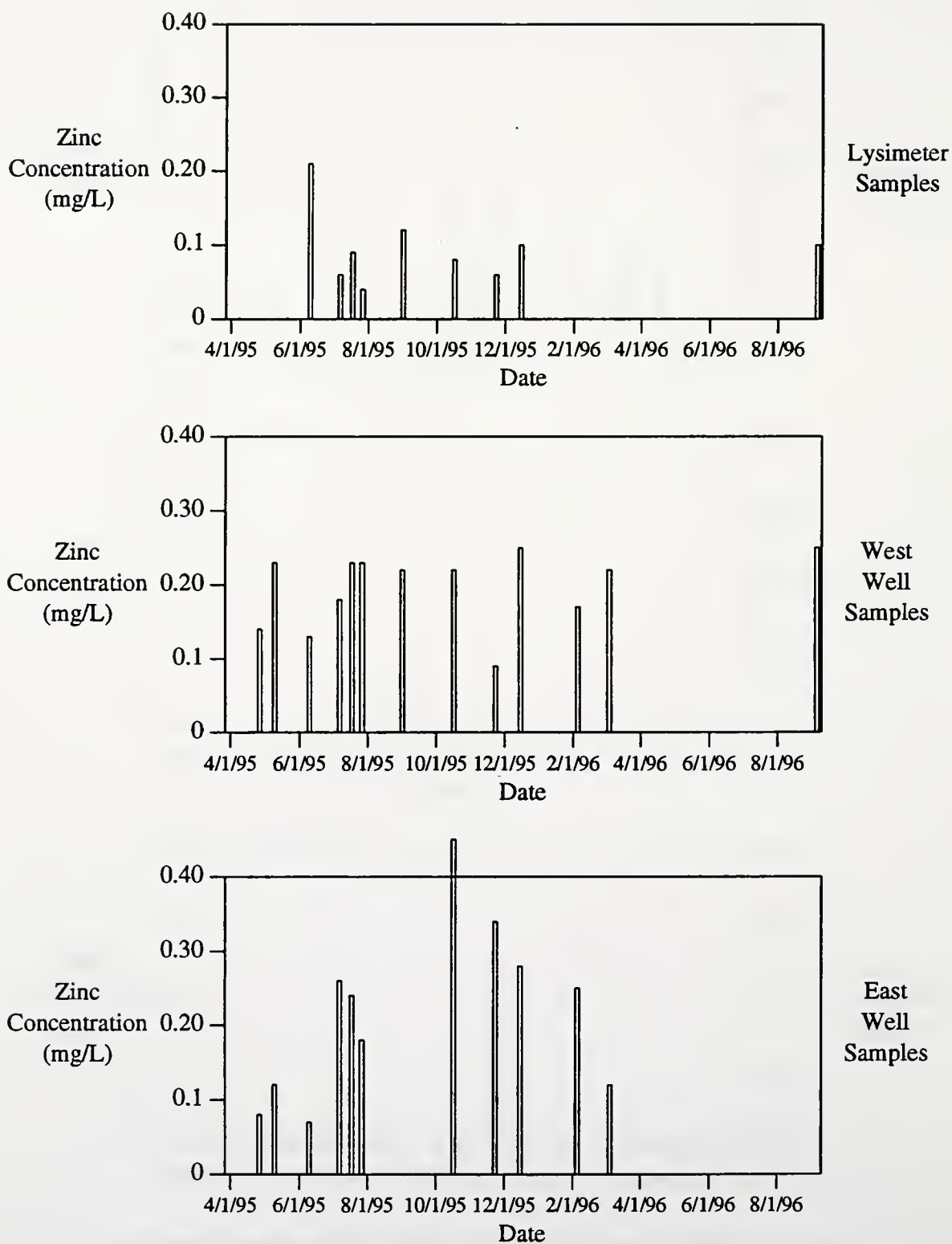


Figure 20. Zinc Concentrations in Well and Lysimeter Samples

West Well Samples (see *Figures 21 and 22*)

The first sample taken at this site (27 April 1995), exhibited a distinct hint of a toxin presence, with Microtox™ levels after 5 and 15 minutes dropping by approximately 40% as compared to the standard control. However, as of 10 May 1995, the Microtox™ results dropped noticeably, and these values have subsequently been low (typically less than 10%). This level appears to be well within an upper control limit previously established for natural sands.

East Well Samples (see *Figures 23 and 24*)

Here again, while the first Microtox™ result (27 April 1995) at this east well was noticeably below the control with both the 5- and 15-minute samples (i.e., with an approximate decline of 40%), all of the subsequent results were far less negative. Beyond June 1995, the Microtox™ results have shown a rather consistent drop of about 10% from the control. Again, this level appears to be well within an upper control limit previously established for natural sands.

Lysimeter Samples (see *Figures 25 and 26*)

The first lysimeter sample (10 June 1995) showed the sort of 'toxicity hint' observed with the initial east and west well samples, with values of about 40%. However, as of July 1995, the observed Microtox™ results were considerably lower, and in most cases subsequently lower, than either of the well samples.

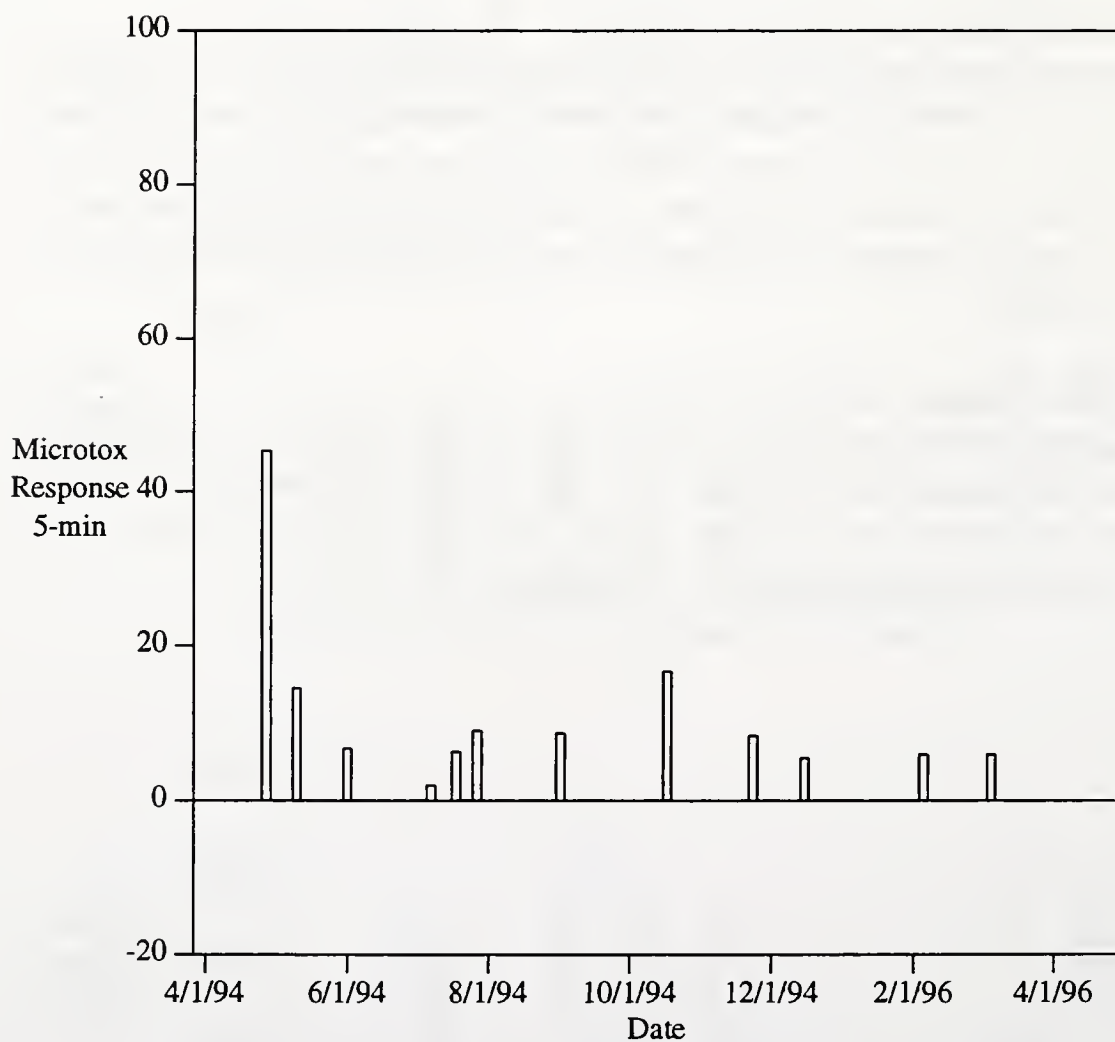


Figure 21. Microtox (5-minute) Response Levels at the East Well

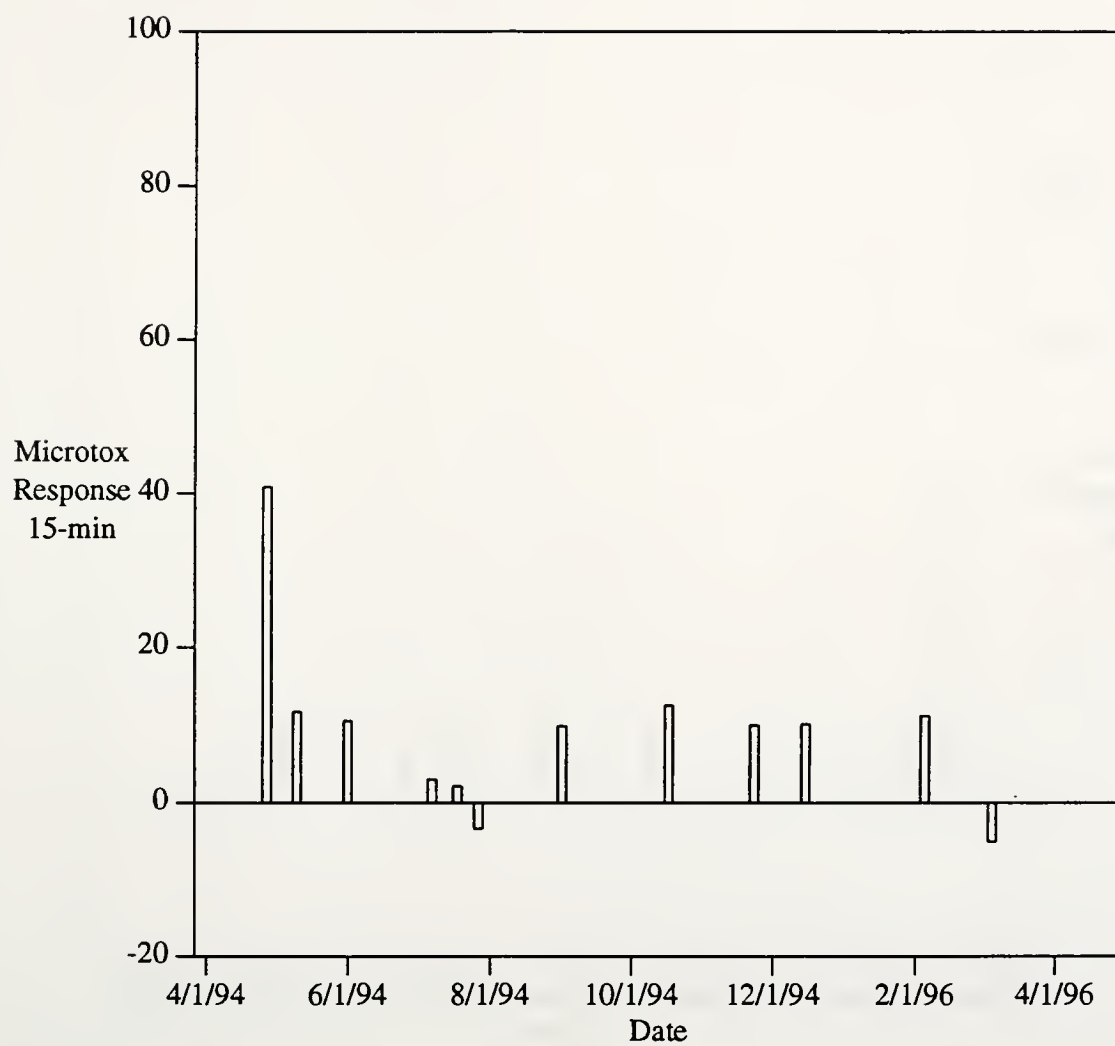


Figure 22. Microtox (15-minute) Response Levels at the East Well

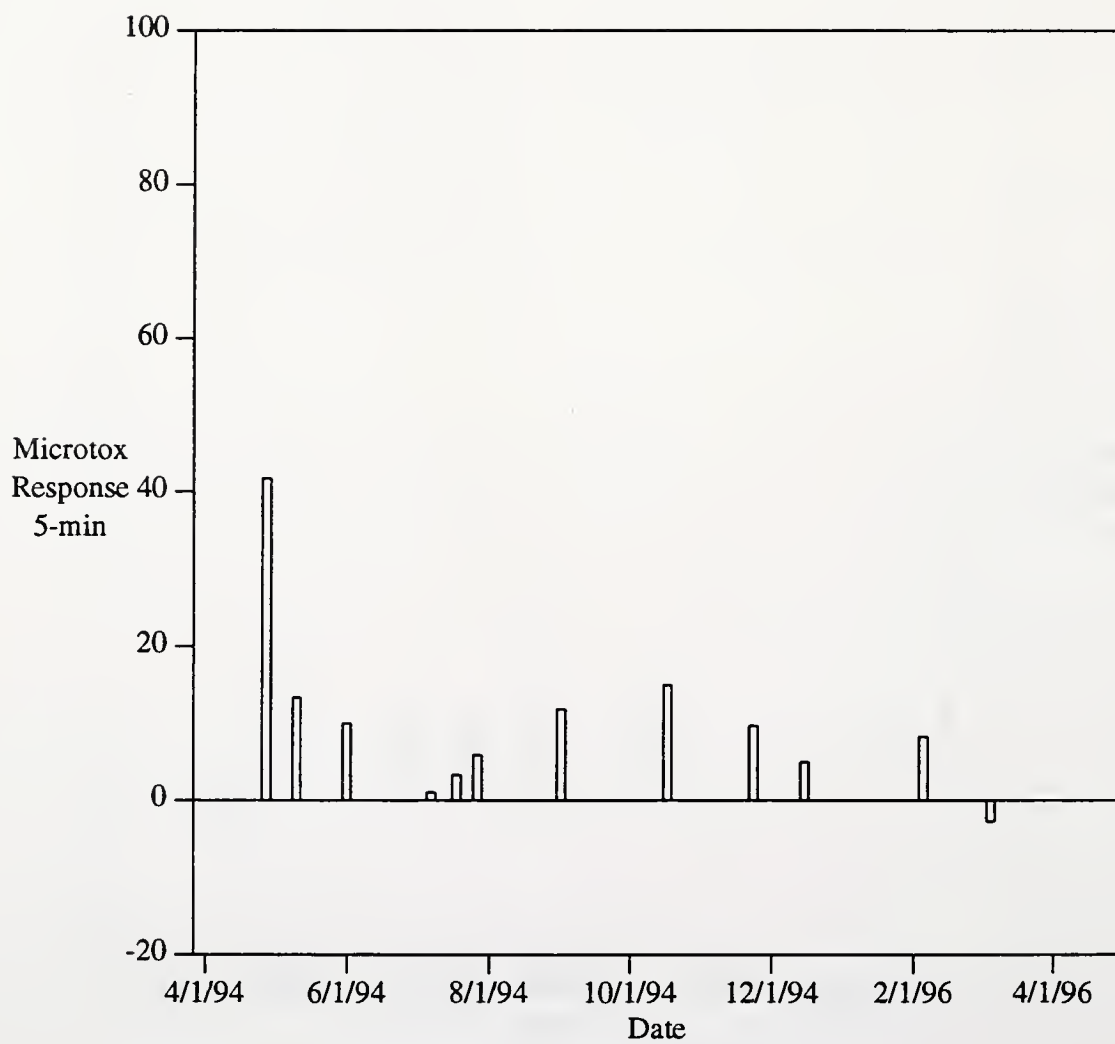


Figure 23. Microtox (5-minute) Response Levels at the West Well

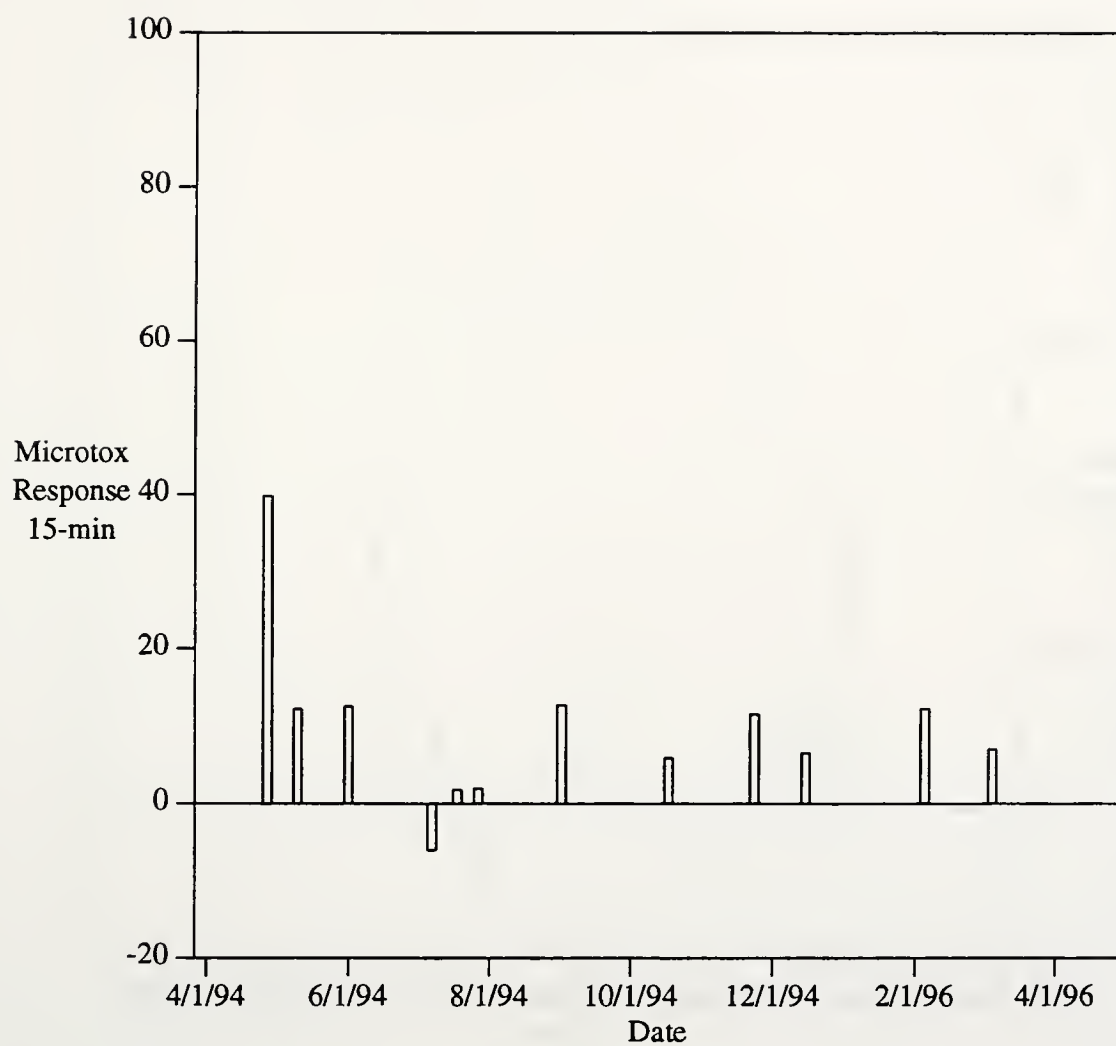


Figure 24. Microtox (15-minute) Response Levels at the West Well

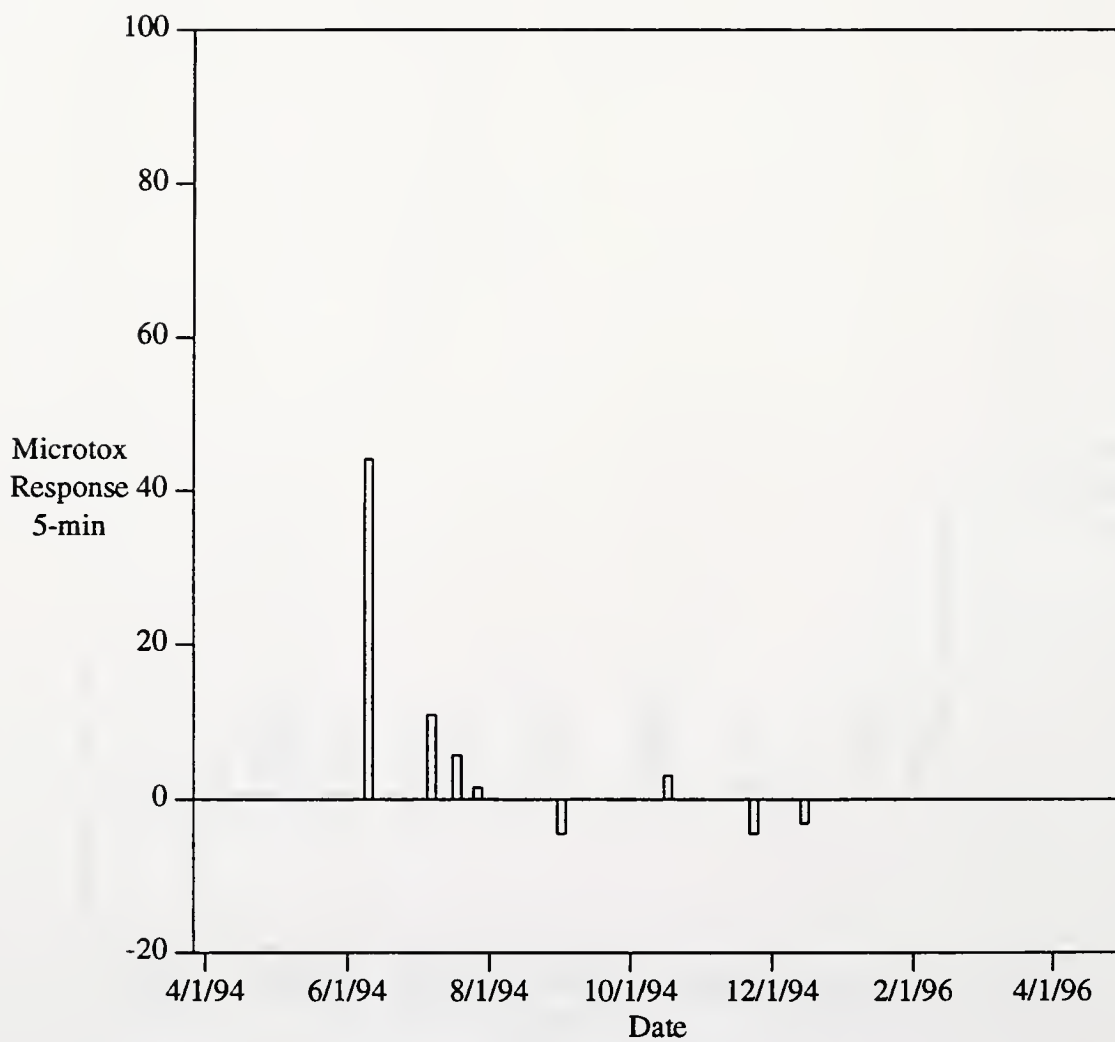


Figure 25. Microtox (5-minute) Response Levels at the Lysimeter

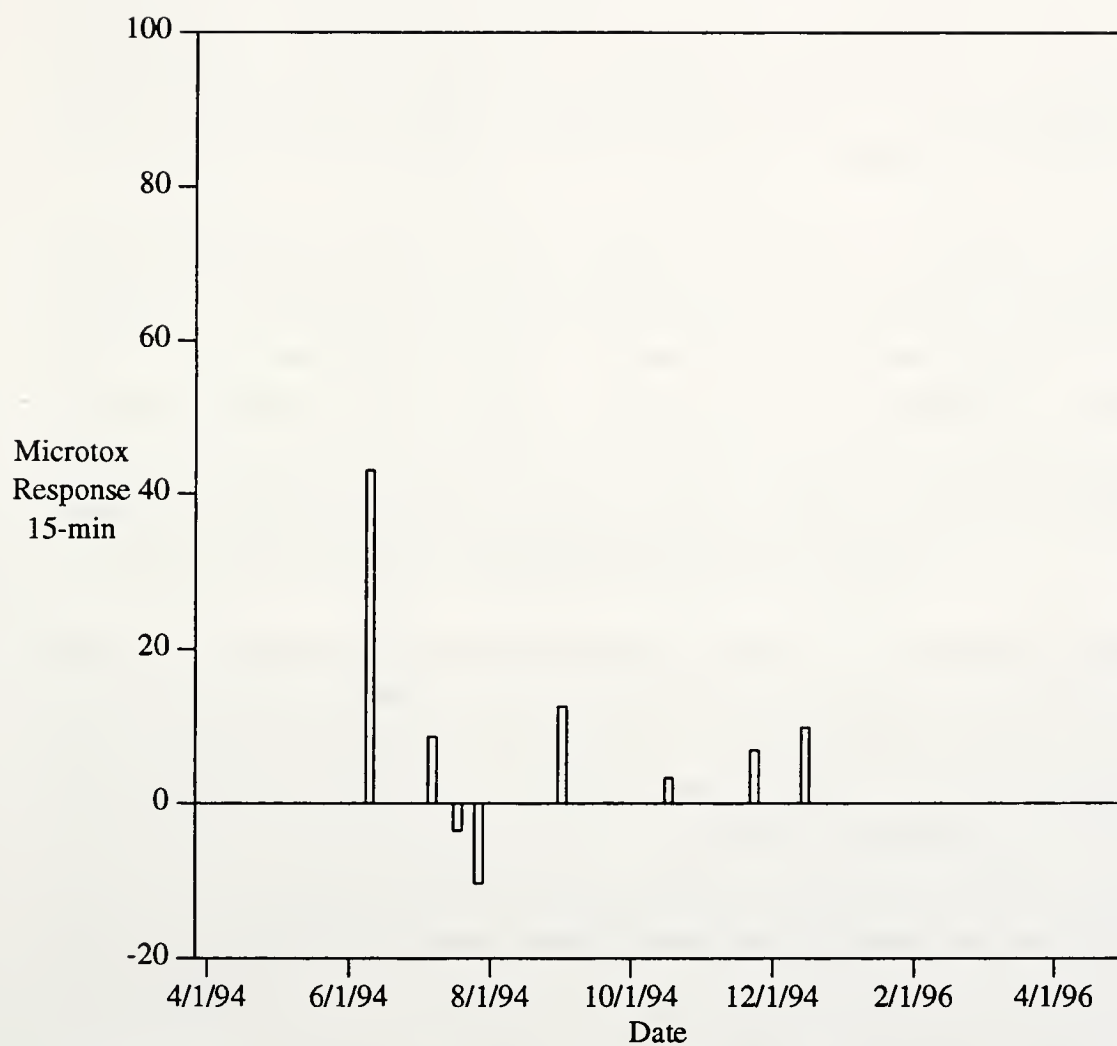


Figure 26. Microtox (15-minute) Response Levels at the Lysimeter

5.2 GEOTECHNICAL ANALYSIS

5.2.1 Compaction

Figure 27 shows the laboratory compaction curve measured from a single Proctor compaction test on a representative sample of the IP&L ponded CCBP used for this project. The curve has a well defined peak similar to the behavior observed for many natural soils. The maximum dry unit weight is 108.4 pcf (17.05 KN/m³) and the optimum water content is 15.7%. If the laboratory compaction effort had been increased (i.e., modified Proctor test), the maximum dry unit weight and optimum moisture content would be expected to increase and decrease, respectively. As one test was conducted, **Figure 27** contains no information regarding the relative homogeneity of the IP&L ponded CCBP.

The field measurements of unit weight from the test circle (**Figure 3**) are listed in **Table 1a**. Sites 1, 2, 5, 6, and 7 were used for the analysis, and sites 3 and 4 were discarded as outliers. The average total unit weight, γ , measured using the nuclear gauge was 118.0 pcf, and the average dry unit weight, γ_d , was 110.3 pcf. The corresponding average values from the sand cone tests were $\gamma = 115.4$ pcf and $\gamma_d = 99.6$ pcf. The calibration factor, γ_{offset} , calculated from wet unit weights is -2.64 pcf. This factor would be added to a nuclear gauge measurement to estimate the wet unit weight in the field.

Table 1b presents the total unit weight measurements taken from four additional locations (sites 8, N-1, N-2, N-3) within the west coal ash embankment using the nuclear density gauge. For each location, γ was corrected using the -2.64 pcf calibration factor. The sand cone unit weights are also shown for comparison. The largest error between the corrected nuclear gauge and sand cone values is 3.65%. A comparison of **Tables 1a** and **1b** shows that the wet unit weight calibration factor (-2.64 pcf) somewhat improves the γ values. However, close agreement between corrected nuclear gauge and sand cone unit weights was not obtained.

Table 2a shows the water contents determined using the laboratory oven, nuclear gauge, stove-top, and Speedy Moisture Meter methods. The nuclear gauge and stove-top methods, on average, underestimate the actual water content by 7.6 and 1.4 percentage points, respectively. The Speedy Moisture Meter, on the other hand, overestimates the actual water content by 1.2 percentage points. The relatively large error of the nuclear

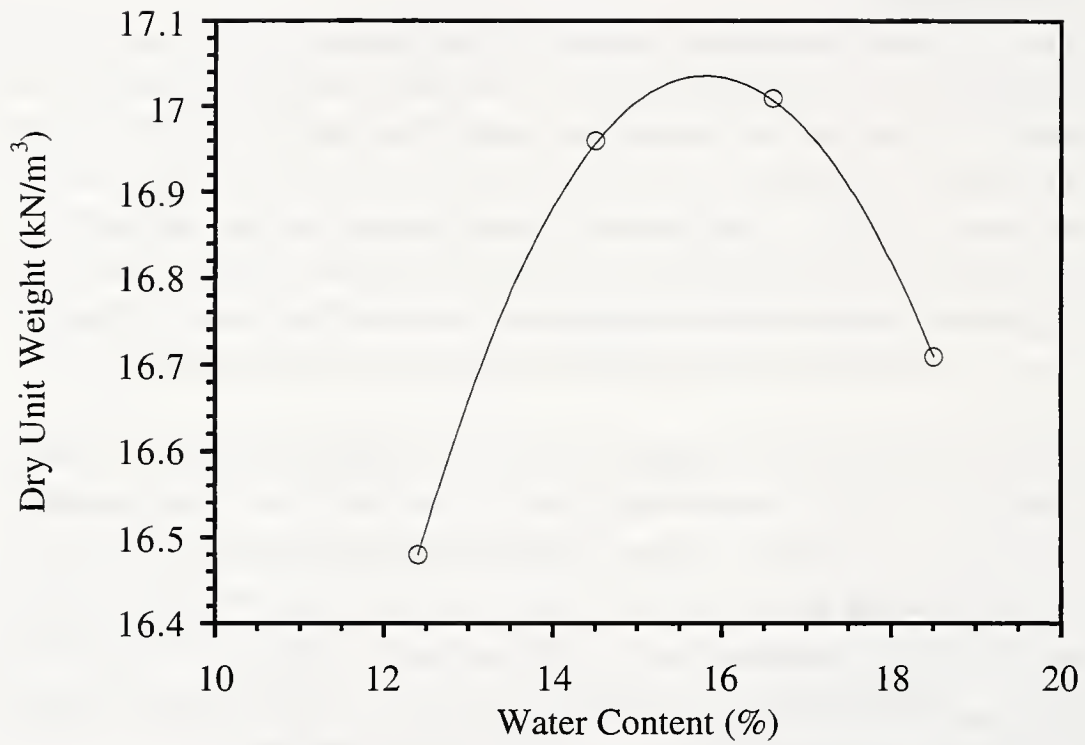


Figure 27 - Standard Proctor Compaction Curve for IP&L Poned CCBP Ash

Table 1a. Comparison of unit weights.

Site	Sand cone, γ (γ_d) (pcf)	Nuclear gauge, γ (γ_d) (pcf)	% error for γ
1	121.8 (105.9)	118.3 (110.9)	2.87
2	108.2 (93.1)	116.4 (108.8)	-7.58
5	117.4 (102.1)	119.5 (112.0)	-1.79
6	112.9 (96.3)	117.3 (109.8)	-3.90
7	116.6 (100.8)	118.6 (110.1)	-1.72
Avg.	115.4 (99.6)	118.0 (110.3)	
γ_{offset}		-2.64	

Table 1b. Comparison of unit weights, random measurements.

Site	Sand cone, γ (pcf)	Nuclear gauge reading, γ (pcf)	Corrected nuclear gauge reading, γ (pcf)	% error for corrected γ
8	120.6	118.8	116.2	3.65
N-1	111.4	117.0	114.4	-2.70
N-2	112.2	115.9	113.3	-0.99
N-3	116.4	116.3	113.7	2.37

Table 2a. Comparison of w%.

Site	Oven dry w%	Nuclear gauge w% (W_w , pcf)	Stove top w%	Speedy w%
1	14.3	6.7 (7.4)		15.0
2	14.4	7.0 (7.6)	11.9	16.3
5	14.2	6.7 (7.5)		15.0
6	16	6.8 (7.5)	14.5	17.2
7	14	7.7 (8.5)		15.6
Avg.	14.6	7.0 (7.7)	13.2	15.8
$w\%_{\text{offset}}$		+7.6	+1.4	-1.2

Table 2b. Comparison of w%, random measurements.

Site	Oven dry w%	Nuclear gauge w% (W_w , pcf)	Corrected nuclear w%	Speedy w%	Corrected speedy w%
8	16.6	8.0 (8.8)	15.6	17.9	16.7
N-1		5.0 (5.6)	12.6	13.1	11.9
N-2		5.1 (5.6)	12.7	11.8	10.6
N-3		5.7 (6.3)	13.3	11.3	10.1

gauge water content measurements are due in part to the error of the nuclear gauge measurements of wet unit weight (which was used to calculate $w\%$ – see Equation 1).

Table 2b shows the water contents obtained from the four addition random tests during construction. An oven was not available at the field site, and it was only possible to measure an oven-dry water content for site 8. For this single measurement (site 8), the correction factors for the nuclear gauge and Speedy Moisture Meter are satisfactory. The data in **Table 2** indicate that, once corrected, water content values measured using the Speedy Moisture Meter are fairly reliable. Thus, the Speedy Moisture Meter can be used to check the water content of CCBP before placement as a means of quality control in the field.

A comparison of **Figure 27** with **Tables 1** and **2** indicate that water contents of the CCBP during compaction were slightly less than the Standard Proctor optimum water content. However, *in-situ* dry unit weights were less than the maximum Proctor value by an average value of 9 pcf.

5.2.2 Settlement

The total settlement of the two settlement plates for the west embankment is shown as a function of time in **Figure 28**. 190 days after installation, the settlement of plates 1 and 2 were 1.4 in. and 2.2 in., respectively. Settlement is larger for plate 2 because it is closer to the overpass bridge where the fill is highest. Settlement rate decreases after construction of the fill is completed. The last few data points show that the foundation soils are undergoing small additional settlements and are nearly in equilibrium with the added load of the west coal ash embankment.

The net compression of the coal ash for the west embankment is shown as a function of time in **Figure 29**. The origin of time for this plot corresponds to the end of embankment construction (14 July 1995). **Figure 29** shows that the coal ash experienced negligible compression or swelling after construction of the embankment. The lack of volume change after construction is a clear advantage for highway projects using ponded coal ash as a borrow source.

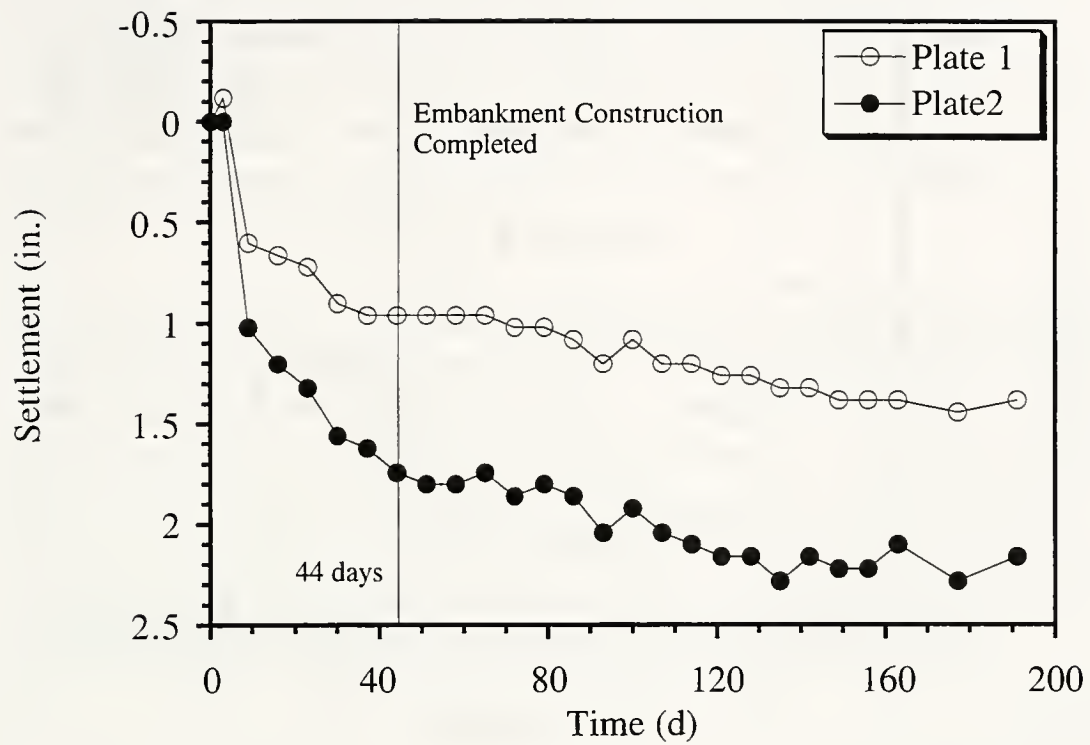


Figure 28 - Settlement of the Base of the West Embankment

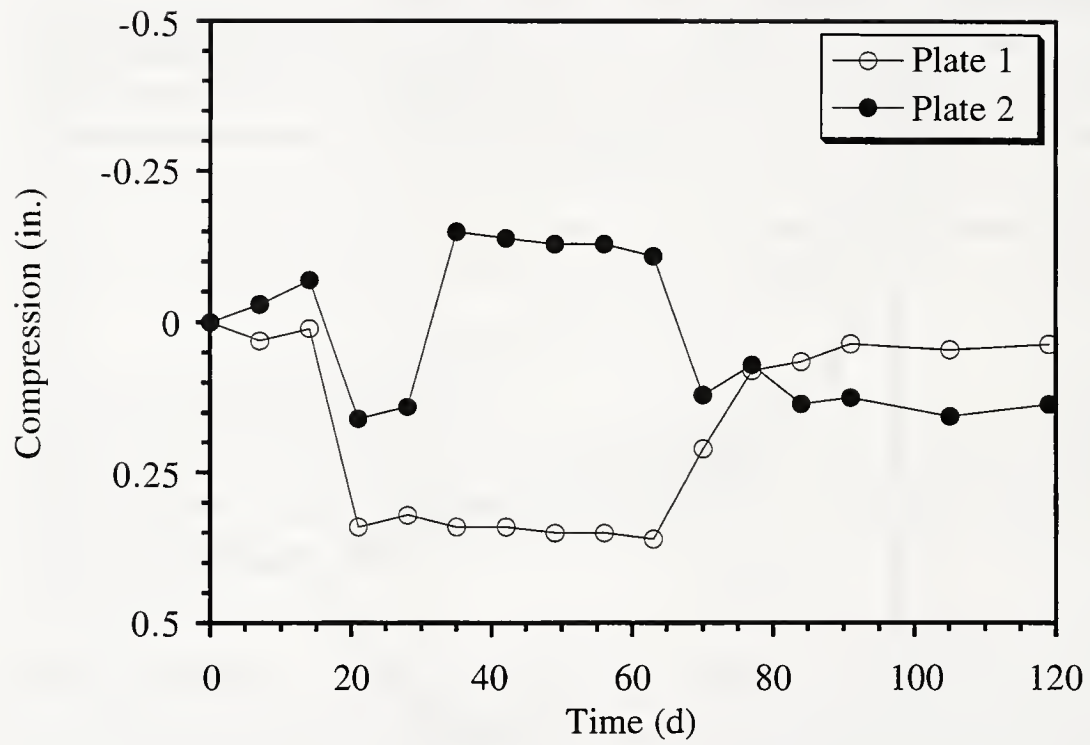


Figure 29 - Net Compression of the West Embankment

5.2.3 *In-Situ* Testing

Appendix C shows the boring logs that were recorded for boreholes SB-1 and SB-2. **Figures 30 and 31** show the water content and SPT blow count (N) as a function of depth within the east and west coal ash embankments. The water content profile for both embankments is similar. For the upper 4 m, the water content generally ranges between 8% and 13%. Below 4m, the water content steadily increases for each fill to about 20%. The higher water contents at the bottom are likely due to capillary rise into the coal ash of water resting on the lower clay encasement.

The SPT blow counts reflect the stratigraphy of the embankments. For each embankment, N is approximately 10 within the upper sandy clay encasement. The underlying coal ash has considerably higher blow counts, ranging between 15 and 35. Using correlation charts developed for natural soils, the density of the ash would then be classified in the range of medium to dense. A range of compaction effort is also suggested by the variability of the blow count data, especially for the east embankment (SB-2). The results of the *in-situ* investigation suggest that, once suitably compacted, the IP&L ponded CCBP has acceptable density and strength for the construction of highway embankments.

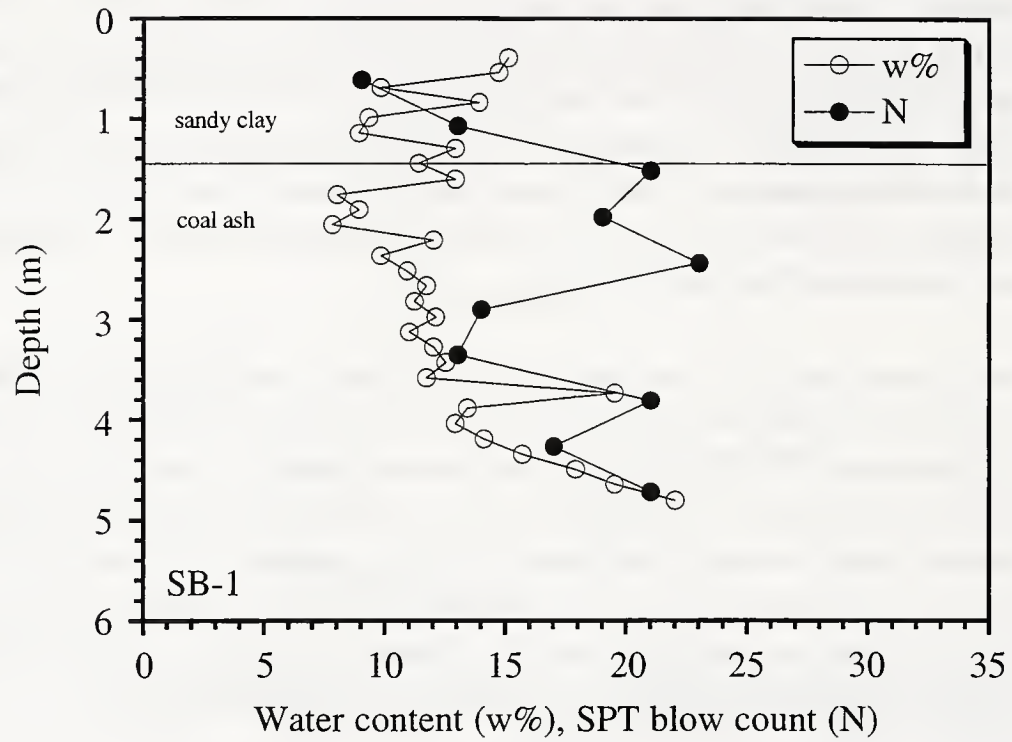


Figure 30 - Boring SB-1: Water Content and SPT Blow Count vs. Depth

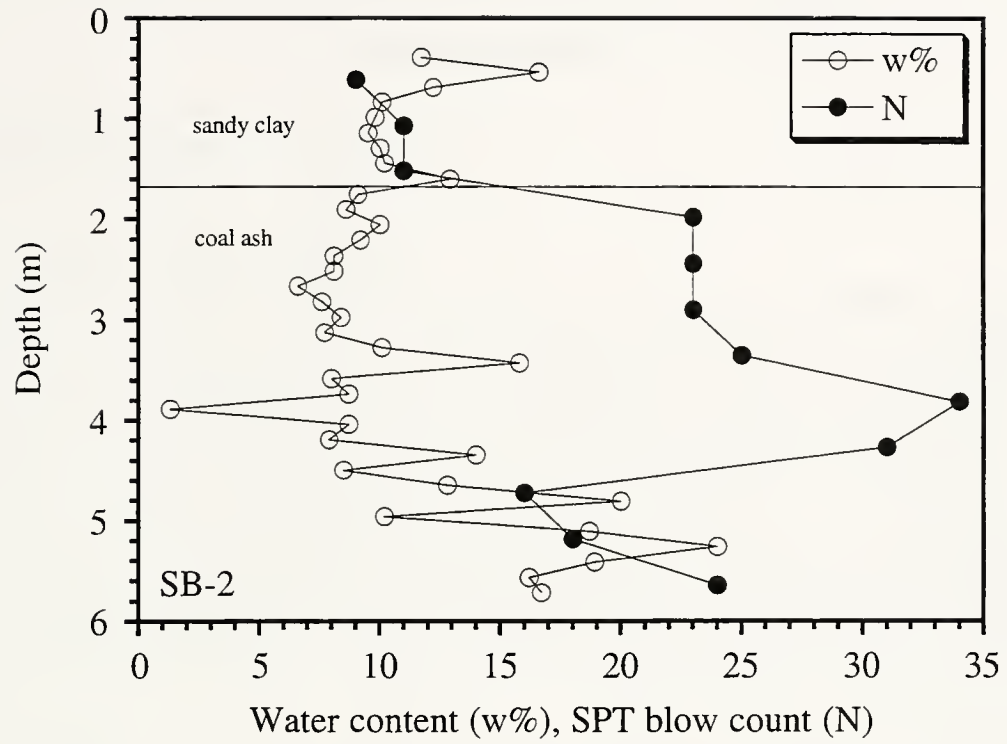


Figure 31 - Boring SB-2: Water Content and SPT Blow Count vs. Depth

CHAPTER 6

CONCLUSIONS

6.1 ENVIRONMENTAL TESTING

6.1.1 Chemical Oxygen Demand

As expected, the employed CCBP residue did not appear to be releasing any sort of organic contaminant. Having been previously combusted within a high-temperature boiler, this ash was likely devoid of any significant levels of leachable organics. However, nominal levels of COD were initially detected in both sampling wells before the ash had been placed. This contamination disappeared, though, after a few months, having likely been flushed from the well by ambient groundwater flow. Although the exact nature of these organic contaminants was never established, it would appear likely that they had been introduced by a mechanism or agent (e.g., release of plasticizer from the plastic well lines) other than the coal ash.

6.1.2 Metals

Overall, this project did not have a significant detrimental impact on the adjacent well waters. Only one (i.e., boron) of the twelve tested metals provided any distinct evidence to suggest that the CCBP had any impact on the adjacent wells.

As of early March 1996, the west well and lysimeter boron levels both appeared to have been elevated by its release from this CCBP material, with the latter well having reached a boron concentration of approximately 10 mg/L. The fact that the CCBP had generated a leachate bearing boron is not at all unexpected, particularly given the anionic (i.e., negatively charged) character of this metal.

Unlike cationic species which exchange on clay surfaces and become immobilized, boron will be mobilized and flushed from the CCBP. The fact that this boron had moved beyond the impermeable layer of cohesive clay placed around the CCBP was, however, an unexpected phenomenon.

Two reasons can be given for this occurrence, with the first being that the latter encapsulating clay cover could have failed either due to poor construction or accident. In

retrospect, though, a second hypothetical '*cause*' appears to be far more likely. Indeed, the embankment's lysimeter system used for collecting discharged leachate could well have been the source of the boron being picked up in the west well.

This leachate, having been directed into a 550 gallon storage tank, was then allowed to discharge on the ground within approximately 5 meters (~15 ft) of this well. The soil in this area appeared to be a highly permeable sandy loam, which could easily have allowed this leachate to contact the groundwater situated at less than a 3 meter (~ nine foot) depth.

This hypothetical circumstance is also supported by the fact that the leachate waters rather consistently exhibited levels of nickel presence in excess of the values found in either well. And whereas the anionically mobile boron had been able to move from the leachate overflow point through the soil to reach the vicinity of the west well, nickel present within these same 'short-circuiting' waters would have been trapped onto the soil due to the effect of cation exchange.

When this project was originally developed, the lysimeter was installed solely as a means to provide routine environmental monitoring of existing leachates. Indeed, during the period of construction, and prior to the eventual placement of a low-permeability cover or pavement over these ash materials, a certain level of leachate discharge through this lysimeter had been anticipated. However, extending beyond these environmental aspects, the release of leachate waters during and immediately after construction also proved to be an important geotechnical issue. Should this water and its corresponding static pressure not be relieved, there is chance that the overlying side-wall (i.e., cohesive cover) materials could actually be laterally displaced, perhaps leading to undesired cracking or failure conditions.

Water which enters the waste during construction, either as natural rainfall or perhaps added to control dust or improve compaction, must consequently be given an opportunity to leach from the emplaced material, at least during and immediately after the period of construction. And with only one such point of 'weep' or lysimeter discharge point being available in the case of the 56th Street project, the release of contaminants like boron is focused into a singular point-source outfall.

Ideally, these released waters would be quickly drained and diluted, to a point where a contaminant like boron would have little if any opportunity to impose a negative

environmental impact. Should this discharge be locally ponded rather than drained, though, sensitive plants in this area might then be correspondingly stressed.

While the latter scenario represents a worst-case circumstance, the potential for any such problem could be sizably diminished simply by spreading this leachate discharge over a broader area. With more of these 'weep' or 'lysimeter' discharge lines being made available, the interstitial waters would both be released faster and in a more distributed (rather than point-source) fashion.

6.1.3 Microtox™ Bioassay

Although the Microtox™ bioassay did reveal an initial 'hint' of toxicity at all three sites, the similarity of the 5- and 15-minute results suggests that the culprit chemical(s) was organic in nature. However, this indication had completely faded by about July 1995. At present, there is no indication whatsoever that the CCBP has, or will, imposed a toxic impact on the adjacent groundwater. In fact, the lysimeter results with this test are almost routinely lower than are the measurements taken with either of the sampling wells. In retrospect, it appears plausible that these initial hints of toxicity could well have been associated with an organic contaminant(s) introduced when installing the wells or lysimeter. For example, plasticizers (e.g., phthalates) or other volatile plastic-related components could have been initially released from the installed piping.

6.2 GEOTECHNICAL TESTING

6.2.1 Compaction

A comparison of the wet unit weights measured using the sand cone and nuclear density gauge shows that, on average, the nuclear gauge (with all offsets disabled) overestimates the wet unit weight of ponded IP&L CCBP by about 2.6 pcf. However, the data is somewhat variable. For this project, the corrected nuclear gauge measurements were typically in error by as much as $\pm 3.5\%$ (4 pcf).

The nuclear gauge and stove-top methods, on average, underestimate the actual water content by 7.6 and 1.4 percentage points, respectively. The Speedy Moisture Meter, on the other hand, overestimates the actual water content by 1.2 percentage points on average. The data obtained in this study indicate that, once corrected, water content values measured

using the Speedy Moisture Meter are considered reliable. Thus, the Speedy Moisture Meter can be used to check the water content of CCBP before placement as a means of quality control in the field.

6.2.2 Settlement

One hundred and ninety days after construction, the total settlement of the foundation soils under the west embankment was as large as 2.2 in. By this time, settlement had nearly ceased for the embankment. The compression of the ash fill itself was negligible after construction was completed.

6.2.3 In-Situ Investigation

Standard Penetration Tests conducted on both the east and west embankments 6 months after construction revealed that the compacted coal ash has a strength and density comparable with many natural borrow materials. The blow counts in the coal ash ranged from about 15 to 35. The water content of the compacted ash ranged from about 10% to 20% over the depth of the fill.

CHAPTER 7

RECOMMENDATIONS

1. Given the observed levels of geotechnical performance, and lack of any significant negative environmental impact, recorded during this study, a recommendation is warranted for INDOT to consider further applications of these coal ash residues for similar 'demonstration' construction projects. INDOT is currently developing special provisions for use of co-mingled CCBP based partly on results of this study.
2. The coal ash residues being considered for future constructive reuse by INDOT should meet either Type III or Type IV criteria.
3. The environmental data obtained during this study suggests that the requirements for a cohesive soil barrier or encasement could be reduced or eliminated. However, given the likely susceptibility of the CCBP to erosion, the use of a natural soil cover bearing appropriate vegetation is recommended.
4. The on-going environmental monitoring effort should be continued on a semi-annual basis extending through 1997, covering both the metal and Microtox™ parameters for the two monitoring wells and lysimeter. At the end of 1997, and should these latter results be similarly nominal in extent, this sampling interval should be eased to an annual test for the next two years...at which point all testing would be suspended unless these new observations created any particular level of concern.
5. In all future projects where on-site monitoring wells and lysimeters are to be installed, the lysimeter overflow should be discharged in a fashion which obviates any potential impact on these wells (i.e., thereby avoiding the sort of contaminant short-circuiting observed during this study).
6. The nuclear density gauge should be used with caution to measure *in-situ* unit weight and water content of CCBP. Until better correlations can be established, nuclear gauge measurements should be regularly checked using the sand cone method (for unit weight) and the Speedy Moisture Meter or standard oven drying procedure (for water content).
7. Once corrected, water content values measured using the Speedy Moisture Meter are considered reliable. Thus, the Speedy Moisture Meter may be used to check the water content of CCBP before placement as a means of quality control in the field.

CHAPTER 8

IMPLEMENTATION SUGGESTIONS

1. INDOT should initiate discussions with Indiana coal ash generators in terms of facilitating and coordinating potential reuse of CCBP for future INDOT highway development projects.
2. INDOT's ongoing development of special provisions for using co-mingled CCBP materials, as based in part on the successful outcome of this project, should proactively catalyze the aforementioned effort.
3. The environmental and geotechnical properties of the CCBPs will need to be tested prior to construction for each application.
4. Based on the expected environmental quality of these CCBP residuals, and their apparent absence of chemical contaminants harmful to human health, consideration should be given to future embankment designs without an underlying liner or encasement material.

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APPENDICES

Appendix A: Environmental Metals Contaminant Levels

East well Metal Levels		Al	Bo	Cd	Co	Cu	Cr
27-Apr	31	0.02	0.07	0	0.01	0.01	0
10-May	44	0	0.08	0	0	0.03	0
10-Jun	75	0	0.04	0	0.04	0	0
7-Jul	102	0.05	0.34	0	0	0	0
18-Jul	113	0	0.27	0	0	0.01	0
27-Jul	122	0.05	0.31	0	0.01	0.02	0
1-Sep	158	0	0.18	0	0	0.02	0
17-Oct	204	0.01	0.34	0	0	0.01	0
13-Nov	241	0.03	0.11	0	0.01	0	0
15-Dec	263	0.03	0.18	0	0	0	0
5-Feb 96	314	0.02	0.37	0	0.03	0.01	0
5-Mar 96	342	0.02	0.89	0	0.01	0	0

		Fe	Mn	Mo	Ni	Pb	Zn
27-Apr	31	0.24	0.28	0.02	0.02	0	0.08
10-May	44	0.22	0.37	0.01	0.02	0	0.12
10-Jun	75	0.23	0.55	0.02	0.03	0	0.07
7-Jul	102	0.14	0.95	0	0.03	0	0.26
18-Jul	113	0.42	1.48	0.02	0	0	0.24
27-Jul	122	0.32	1.31	0.02	0.02	0	0.18
1-Sep	158	0.28	1.11	0	0	0	0
17-Oct	204	0.33	1.22	0.04	0	0.01	0.45
13-Nov	241	0.25	0.78	0.03	0	0	0.34
15-Dec	263	0.19	0.44	0.02	0.01	0	0.28
5-Feb 96	314	0.21	0.33	0	0	0	0.25
5-Mar 96	342	0.1	0.15	0.01	0	0	0.12

**West
well
Metal
Levels**

		Al	Bo	Cd	Co	Cu	Cr
27-Apr	31	0.12	0.3	0	0	0	0
10-May	44	0.05	0.47	0	0	0.01	0
10-Jun	75	0	1.3	0	0	0.01	0
7-Jul	102	0.11	1.91	0	0	0.01	0
18-Jul	113	0.52	3.53	0	0	0.01	0
27-Jul	122	0.52	3.53	0	0	0.01	0
1-Sep	158	0.36	4.27	0.01	0	0.02	0
17-Oct	204	0	5.2	0.01	0	0.02	0
13-Nov	241	0.13	7.22	0	0	0	0
15-Dec	263	0.08	8.98	0.01	0	0	0
5-Feb 96	314	0.11	9.14	0	0	0.02	0
5-Mar 96	342	0.17	0.85	0.01	0	0.01	0
5-Sep 96	526	0	8.74	0	0	0	0
		Fe	Mn	Mo	Ni	Pb	Zn
27-Apr	31	0.08	0.02	0.03	0	0.01	0.14
10-May	44	0.06	0.01	0.01	0.01	0.02	0.23
10-Jun	75	0.06	0.03	0.02	0.01	0.03	0.13
7-Jul	102	0.15	0.03	0.01	0.02	0.01	0.18
18-Jul	113	0.07	0.08	0.03	0	0	0.23
27-Jul	122	0.07	0.08	0.03	0	0	0.23
1-Sep	158	0.18	0.1	0.02	0.03	0.02	0.22
17-Oct	204	0.25	0.12	0.03	0	0.03	0.22
13-Nov	241	0.29	0.28	0.01	0	0	0.09
15-Dec	263	0.18	0.34	0.02	0	0	0.25
5-Feb 96	314	0.15	0.41	0.04	0.03	0.01	0.17
5-Mar 96	342	0.22	0.42	0.03	0.04	0	0.22
5-Sep 96	526	0	0	0	0	0	0.25

**Lysimeter
Metal Levels**

		Al	Bo	Cd	Co	Cu	Cr
10-Jun	75	0.07	8	0	0	0	0.01
7-Jul	102	0.12	8.64	0.01	0.01	0	0
18-Jul	113	0.11	8.04	0.02	0	0.01	0.01
27-Jul	122	0.13	7.85	0	0	0	0
1-Sep	158	0.08	7.32	0.01	0.01	0	0
17-Oct	204	0.07	8.66	0	0	0	0
13-Nov	241	0.06	9.01	0.01	0.01	0.03	0.01
15-Dec	263	0.12	9.3	0	0.01	0	0
5-Sep 96	526	0	13.05	0	0	0	0
		Fe	Mn	Mo	Ni	Pb	Zn
10-Jun	75	0.28	0.36	0.02	0	0.06	0.21
7-Jul	102	0.14	0.23	0.02	0.15	0.09	0.06
18-Jul	113	0.18	0.2	0.01	0.1	0.1	0.09
27-Jul	122	0.46	0.26	0.01	0	0.05	0.04
1-Sep	158	0.31	0.23	0.01	0.14	0.13	0.12
17-Oct	204	0.59	0.2	0	0.17	0.11	0.08
13-Nov	241	0.46	0.11	0.01	0.19	0.07	0.06
15-Dec	263	0.27	0.13	0.02	0.11	0.04	0.1
5-Sep 96	526	0.0	0.0	0	0.0	0.0	0.1

Appendix B: Environmental Microtox™ Response Levels

Well Microtox Response		East well 5-min response	East well 15-min response	West well 5-min response	West well 15-min response
27-Apr	31	45.3	40.8	41.7	39.8
10-May	44	14.4	11.6	13.2	12.1
1-Jun	66	6.7	10.4	9.9	12.4
7-Jul	102	2	3	1	-6
18-Jul	113	6.3	2.1	3.2	1.7
27-Jul	122	9	-3.4	5.8	1.9
1-Sep	158	8.7	9.8	11.7	12.6
17-Oct	204	16.6	12.4	14.8	5.8
13-Nov	241	8.3	9.9	9.5	11.4
15-Dec	263	5.5	10	4.9	6.4
5-Feb 96	314	6	11.1	8.2	12.1
5-Mar 96	342	6	-5.1	-2.8	6.9

Lysimeter Microtox Response		5-min response	15-min response
10-Jun	75	44.1	43.1
7-Jul	102	10.8	8.6
18-Jul	113	5.6	-3.6
27-Jul	122	1.5	-10.4
1-Sep	158	-4.5	12.5
17-Oct	204	3	3.2
13-Nov	241	-4.5	6.8
15-Dec	342	-3.2	9.8

Appendix C: Geotechnical Boring Logs

Boring logs provided by Nayyar Zia of INDOT.

INDIANA DEPARTMENT OF TRANSPORTATION

PROJECT NO. STI-465-4() DES. NO. 8033230 BORING NO. SB-1
 STRUCTURE NO. N/A COUNTY: MARION ROAD NO. WEST 56th STR
 PROJECT LOCATION: WEST 56th STREET AT I-465 ELEVATION: 258.99m
 STATION/OFFSET/LINE: 20+67/19.20m LT/LINE "S-56" START: 11/21/95
 BORING METHOD & RIG TYPE: HSA / TRUCK FINISH: 11/21/96
 WATER DEPTH @ COMP. DRY : AFTER HRS. CAVED @ 3.20 m

ELEVATION DEPTH	SOIL SYMBOLS SAMPLER SYMBOLS AND FIELD TEST DATA	Description	Remarks	SAMPLE NO.	RECOV (%)	GP= tsf
259.0		ASPHALT				
258.5	3/6 4/6 5/6	BROWN, DRY, SANDY CLAY WITH TRACE OF GRAVEL (VISUAL)		SS-1	95	
258.0	4/6 5/6 8/6	BROWN, DRY, MEDIUM STIFF SANDY CLAY LOAM WITH TRACE OF GRAVEL (VISUAL)		SS-2	95	
257.5	4/6 8/6 13/6			SS-3	100	
257.0	9/6 10/6 9/6	DARK GRAY TO BLACK, DRY, MEDIUM DENSE COAL COMBUS- TION BY PRODUCT WITH SAND		SS-4	90	
256.5	10/6 12/6 11/6			SS-5	100	
256.0	4/6 6/6 8/6			SS-6	100	
255.5	4/6 5/6 7/6			SS-7	100	
255.0	9/6 10/6 11/6			SS-8	100	
254.5	8/6 8/6 9/6			SS-9	100	
254.0	9/6 10/6 11/6	DARK GRAY TO BLACK, WET, MEDIUM DENSE COAL COMBUS- TION BY PRODUCT WITH SAND BOTTOM OF THE TEST HOLE 4.88 m		SS-10	100	

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 WEATHER: CLOUDY TEMPERATURE: 1 c PAGE OF

INDIANA DEPARTMENT OF TRANSPORTATION

PROJECT NO. STI--465-4() DES. NO. 8033230 BORING NO. SB-2
 STRUCTURE NO. N/A COUNTY: MARION ROAD NO. WEST 56th STR
 PROJECT LOCATION: WEST 56th STREET AT I-465 ELEVATION: 258.60m
 STATION/OFFSET/LINE: 25+66/19.81m LT/LINE "S-56" START: 11/21/95
 BORING METHOD & RIG TYPE: HSA / TRUCK FINISH: 11/21/96
 WATER DEPTH @ COMP. DRY : AFTER HRS. CAVED @ 4.11 m

ELEVATION DEPTH	SOIL SYMBOLS SAMPLER SYMBOLS AND FIELD TEST DATA	Description	Remarks	SAMPLE NO.	REC'DV. (%)	OP- tsf
259						
258.5	0	ASPHALT				
258	0.5	BROWN, DRY SANDY CLAY (VISUAL)		SS-1	100	
257.5	1	BROWN TO GRAY, DRY, MEDIUM STIFF SANDY CLAY WITH TRACE OF GRAVEL (VISUAL)	STIFF AT 0.76 m SAND SEAM AT 0.91 TO 1.07 m	SS-2	100	
257	1.5	BROWN, DRY, STIFF SANDY CLAY WITH SANDY CLAY LOAM LAYERS (VISUAL)		SS-3	100	
256.5	2	DARK GRAY TO BLACK, DRY, MEDIUM DENSE COAL COMBUS- TION BY-PRODUCT WITH SAND	DENSE AT 2.13 m	SS-4	95	
256	2.5			SS-5	95	
255.5	3	DARK GRAY TO BLACK, DRY, MEDIUM DENSE COAL COMBUS- TION BY-PRODUCT WITH SAND		SS-6	100	
255	3.5			SS-7	100	
254.5	4	DARK GRAY TO BLACK, DRY, MEDIUM DENSE COAL COMBUS- TION BY-PRODUCT WITH SAND		SS-8	100	
254	4.5			SS-9	95	
253.5	5	DARK GRAY TO BLACK, DRY, MEDIUM DENSE COAL COMBUS- TION BY-PRODUCT WITH SAND		SS-10	100	
253	5.5			SS-11	95	
		DK GRAY TO BLK, SLT MOIST, MED DENSE COAL COMBUSTION BY-PRODUCT WITH SAND BOTTOM OF THE TEST HOLE 5.79 m		SS-12	100	

DRILLER: DENNIS TORRANCE INSPECTOR: PAT MARTIN DATUM: USC & GS
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